JOURNAL OF THE AERONAUTICAL SCIENCES

VOLUME 4 JUNE, 1937 NUMBER 8

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Published by the

INSTITUTE OF THE AERONAUTICAL SCIENCES, INC.

JOURNAL OF THE AERONAUTICAL SCIENCES

VOL. 4 JUNE, 1937 NO. 8

Editor: J. C. HUNSAKER, *Massachusetts Institute of Technology*

PUBLISHED MONTHLY BY THE INSTITUTE OF THE AERONAUTICAL SCIENCES, INC.
AT 20TH AND NORTHAMPTON STS., EASTON, PA.

The JOURNAL OF THE AERONAUTICAL SCIENCES is the official publication of the Institute of the Aeronautical Sciences, Inc., and prints papers of scientific and technical interest to members and subscribers. In general, it provides an opportunity for members to publish articles disclosing new knowledge and new applications in the field of the aeronautical sciences. The Journal prints a few complete professional papers in each issue and a large number of short notes and critical comments. The Journal restricts itself to the aeronautical aspects of advances in science and engineering. New knowledge in physics, metallurgy, meteorology, etc., having aeronautical applications is reported and discussed in the Journal. Papers read at meetings of the Institute are presented in full or digested. Reviews of aeronautical literature and a digest of current aircraft books and magazines form a section of the publication. The news of the Institute is furnished members through the Journal.

SUBSCRIPTION RATES

United States and Possessions		Foreign Countries, Including Canada	
1 Year	$5.00	1 Year	$6.00
Single Copies	.50	Single Copies	.60

Manuscripts for publication, proofs, and all correspondence should be addressed to the Editorial Secretary of the JOURNAL.

Correspondence regarding subscriptions may be addressed to Publication Office, 20th and Northampton Sts., Easton, Pa., or to the Editorial Office of the JOURNAL OF THE AERONAUTICAL SCIENCES, 5431 R. C. A. Building, Rockefeller Center, New York, New York. Cable Address: INSAEROSCI.

Entered as Second Class Matter at the Post Office, Easton, Pa., May 1, 1937. Acceptance for mailing at a special rate of postage provided for in the Act of August 24, 1912. Authorized April, 29, 1937.

JOURNAL OF THE AERONAUTICAL SCIENCES

Volume 4 JUNE, 1937 Number 8

The Statistical Theory of Isotropic Turbulence

G. I. TAYLOR, *Royal Society, London*

(Received May 1, 1937)

SUMMARY

Measurements made by L. F. G. Simmons at the National Physical Laboratory, Teddington, verify very completely the relationship between the correlation functions R_1 and R_2 which has been predicted by Th. von Kármán.[1]

Assuming that the shape of the correlation curve does not change with time, von Kármán's theory predicts a definite correlation curve when the dissipation of energy is known. All the data necessary for calculating this curve are available in the form of measurements of $\overline{u^2}$ at points downstream from a grid in a wind tunnel. The calculated curve for R_1 is very different from the observed curve. It is very much smaller in extent. For instance in the case where measurements were made the correlation between the values of u at points 1 in. apart predicted by von Kármán's theory is less than 0.01, whereas the observed correlation is 0.35.

The calculated curve also differs from the observed curve in that when $\overline{u^2}/U^2$ is independent of the speed U of the tunnel, von Kármán's theory predicts that the scale of the R_1 curve should be proportional to $U^{-1/2}$ whereas the observed R_1 curve is found to remain unchanged as U varies.

IN A VERY interesting paper von Kármán has extended the author's statistical theory of isotropic turbulence in several directions. In particular he has shown that the correlations between components of velocity at two points, A and B, distant r apart, may be expressed in terms of two correlation functions, R_1 and R_2, which are functions of r only. R_1 is the correlation between the turbulent components of A and B when resolved along the line AB while R_2 is the correlation when resolved in any direction perpendicular to AB. Von Kármán has proved the following relationship between R_1 and R_2:

[1] Th. von Kármán, *The Fundamentals of the Statistical Theory of Turbulence*, Journal of the Aeronautical Sciences, Vol. 4, No. 4, February, 1937.

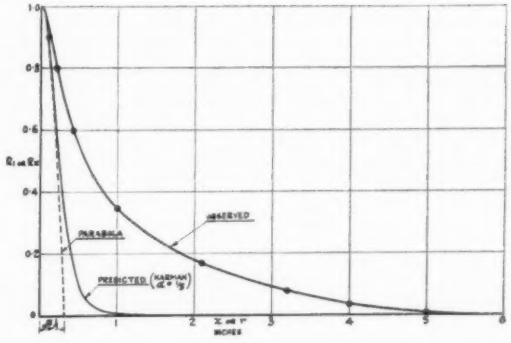

FIG. 1.

$$r\frac{dR_1}{dr} + 2(R_1 - R_2) = 0 \qquad (1)$$

On reading this result the author realized that he had in his possession the material for submitting this relationship to experimental test. At the National Physical Laboratory, L. F. G. Simmons has recently measured the quantities which in the notation of the author's paper were R_x and R_y in an air stream rendered turbulent by a 3 × 3 in. mesh grid. The definitions of R_1 and R_2 show that R_1 is the same function of r that R_x is of x, and that R_2 is the same function of r that R_y is of y. In Fig. 1 the measured values of R_x are shown for a range of values of x. Since the $R_x(x)$ and the $R_1(r)$ curves are identical it is possible to find $r\frac{dR_1}{dr}$ graphically, from the measured curve. This has been done and the values of $R_1 + \frac{1}{2}r\frac{dR_1}{dr}$, which

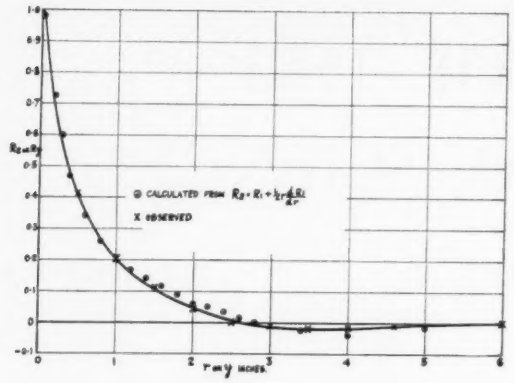

FIG. 2.

according to Eq. (1) should be equal to R_2, have been calculated. These calculated points are marked in Fig. 2 and the measured values of R_2 are also set down. It will be seen that the two sets of points lie on the same curve, thus verifying that Eq. (1) is a true relationship for the turbulence produced in a wind tunnel by a grid.

Von Kármán next uses the equations of motion in a novel manner in order to find an equation for R_1. If u, v, w are the component velocities at A and u', v', w' those at B, it may be supposed that B is fixed while A varies its position. Multiplying an equation of motion at A by u', v', or w' and taking average values, von Kármán gets the tensor equation

$$\frac{\partial}{\partial t}(R_{ik}\overline{u^2}) = 2\nu\overline{u^2}\Delta(R_{ik}) \tag{2}$$

where $\Delta = \dfrac{\partial^2}{\partial\xi^2} + \dfrac{\partial^2}{\partial\eta^2} + \dfrac{\partial^2}{\partial\zeta^2}$ when ξ, η, ζ are the projections of AB on the axes.

From Eq. (2) von Kármán deduces the scalar equation

$$\frac{\partial}{\partial t}(R_1\overline{u^2}) = 2\nu\overline{u^2}\left(\frac{d^2R_1}{dr^2} + \frac{4}{r}\frac{dR_1}{dr}\right) \tag{3}$$

If one of the scalar equations of motion is multiplied by u' and averages taken, then

$$\overline{u'\frac{\partial u}{\partial t}} + \overline{uu'\frac{\partial u}{\partial x} + u'v\frac{\partial u}{\partial y} + u'w\frac{\partial u}{\partial z}} = -\frac{\overline{u'\dfrac{\partial p}{\partial x}}}{\rho} + \nu\Delta\overline{uu'} \tag{4}$$

and similarly

$$\overline{u\frac{\partial u'}{\partial t}} + \overline{uu'\frac{\partial u'}{\partial x} + uv'\frac{\partial u'}{\partial y} + uw'\frac{\partial u'}{\partial z}} = -\frac{\overline{u\dfrac{\partial p}{\partial x}}}{\rho} + \nu\Delta\overline{uu'} \tag{5}$$

On adding Eqs. (4) and (5) and taking A and B on a line parallel to the axes of x

$$\frac{\partial}{\partial t}(\overline{uu'}) = \frac{\partial}{\partial t}(R_1\overline{u^2}), \text{ and } \Delta(\overline{uu'}) = \overline{u^2}\left(\frac{d^2R_1}{dr^2} + \frac{4}{r}\frac{dR_1}{dr}\right)$$

so that von Kármán's scalar Eq. (3) can be proved to be true if

$$\overline{u'\frac{\partial p}{\partial u} + u\frac{\partial p'}{\partial x}} = 0$$

and if the mean values of the "inertia" terms in Eqs. (4) and (5) containing three components, is zero.

It is difficult to see any *a priori* reason why these inertia terms in Eqs. (4) and (5) should be zero. On the other hand they are certainly zero when A coincides with B, for then

$$u'u\frac{\partial u}{\partial x} + u'v\frac{\partial u}{\partial y} + u'w\frac{\partial u}{\partial z} = u^2\frac{\partial u}{\partial x} + uv\frac{\partial u}{\partial y} + uw\frac{\partial u}{\partial z}$$

and taking account of the equation of continuity, this can be written

$$\tfrac{1}{2}\left\{\frac{\partial}{\partial x}(u^3) + \frac{\partial}{\partial y}(u^2v) + \frac{\partial}{\partial z}(u^2w)\right\} \tag{6}$$

When the mean value is taken, each term of Eq. (6) evidently vanishes. It appears therefore that Eq. (3) is true in the limit when $r = 0$, and in fact in this case von Kármán shows that Eq. (3) reduces to

$$\frac{d}{dt}(\overline{u^2}) = 10\nu\,\overline{u^2}\left(\frac{d^2R_1}{dr^2}\right)_{r=0} = \frac{-10\nu\overline{u^2}}{\lambda^2} \tag{7}$$

This is the equation for decay of turbulence which the author had already proved by another quite independent method. Von Kármán promises to give the proof that the mean values of the inertia terms in Eqs. (4) and (5) vanish when A and B are not coincident in another paper.

Von Kármán next shows that in a certain class of solutions of Eq. (3) t and r can be separated. If $X = r/\sqrt{\nu t}$, and it is assumed that R_1 is a function of X only, Eq. (3) becomes

$$\frac{d^2R_1}{dX^2} + \left(\frac{4}{X} + \frac{X}{4}\right)\frac{dR_1}{dX} + 5\alpha R_1 = 0 \tag{8}$$

where

$$\alpha = \left(\frac{d^2R_1}{dX^2}\right)_{r=0}$$

The assumption implies, first, that the $R_1(r)$ curve is of the same shape for all time, though its scale increases as $\overline{u^2}$ decreases, and second that the turbulent velocity falls off with time in accordance with the relationship

$$\frac{\overline{u_0^2}}{\overline{u^2}} = \left(1 + \frac{t}{t_0}\right)^{10\alpha} \tag{9}$$

or if the turbulence is produced in an air stream by a grid,

$$\frac{\overline{u_0^2}}{\overline{u^2}} = \left(1 + \frac{x}{Ut_0}\right)^{10\alpha} \tag{10}$$

where x is the distance measured downstream from the place where $\overline{u^2} = \overline{u_0^2}$.

Since the observations necessary for testing these relationships had already been made but have not been published, it seems useful to publish them at this stage.

Before describing how the observations can be used, it is necessary to explain how they were made. To measure the correlation between the turbulent components u and u' at A and B, hot wires about 1 mm. long and 10^{-4} in. in diameter (with resistance about 30 ohms per mm.) were set up at the two points.

The correlations were measured either by passing the currents from the hot wire bridges through amplifiers and then passing the outputs through the two coils of an electrodynamometer or by another method which has been described by the author.[2] In all cases compensation for the thermal lag of the wires was made by the method introduced by Dryden.

To measure R_2 the wires were placed in a line perpendicular to the air stream in a wind tunnel. To produce the turbulence a square mesh grid of regularly spaced round bars or strips was set up near the entrance to the tunnel. To measure R_1 it is theoretically necessary to set one hot wire downstream of the other, but it was found that very little error was introduced by arranging the hot wires so that the line between them was inclined at 15° to the axis of the tunnel. Indeed, von Kármán's theory enables the calculation of the error due to using measurements taken in a line 15° out of true as though they were in the true direction. The error is very small.

Measurements of $\overline{u^2}$, R_1, and R_2 were made at wind speeds U ranging from 15 to 35 ft. per sec. It was found that when the hot wire was in any given position $\overline{u^2}/U$ is nearly constant as U varies. In this respect the measurements are in agreement with those of Dryden. It was also found that if the two hot wires are fixed, the correlation between their indications does not depend to any measureable extent on U except when the wires are very close together and the correlation is nearly 1.0.

Now consider these facts in relation to von Kármán's theory. Since $\overline{u^2}/U^2$ does not depend on U, Eq. (10) shows that α must be constant as U varies. Since α is constant it will be seen from Eq. (8) that the shape of the $R_1(r)$ curve does not vary as U varies.

Since $\overline{u^2}/U^2$ is constant at every fixed point

$$\frac{1}{\overline{u^2}}\frac{d}{dt}(\overline{u^2}) = \frac{U}{\overline{u^2}}\frac{d\overline{u^2}}{dx}$$

must be proportional to U. Hence, from Eq. (7),

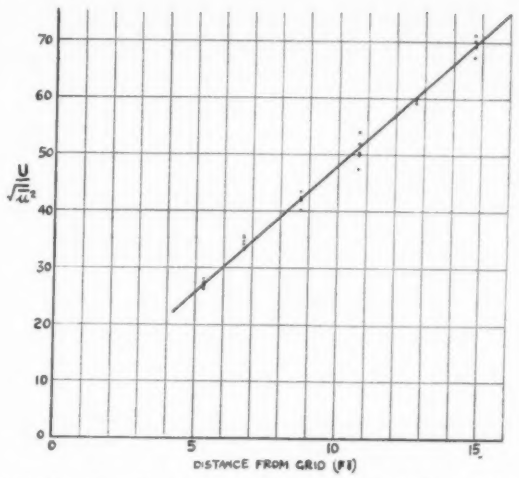

FIG. 3. Turbulence measurements behind 3 × 3 in. grid.

$1/\lambda^2$ is proportional to U. Von Kármán's assumption that the shape of the R_1 curve depends only on α therefore necessitates the conclusion that as U increases, the scale of the R_1 curve must be proportional to $U^{-1/2}$. Since careful experiments have failed to detect any systematic change in R_1 with U when the hot wires are kept fixed, it seems that there is definite proof that the assumption, that the $R_1(r)$ curve preserves its shape, does not in fact apply to the turbulence produced in wind tunnels by regularly spaced grids.

Comparison between Theoretical and Observed $R_1(r)$ Curves

The conclusion just reached is confirmed when the measured values of R_1 are compared with those predicted by Eq. (8). The measurements of R_1 shown in Fig. 1 were made in a stream of wind made turbulent by passing through a grid which was specially designed to prevent the turbulence in the air upstream of the grid from passing through it. The grid consisted of flat strips arranged in a square latticework of 3 × 3 in. mesh. A very deep honeycomb made with square 3 × 3 in. cells each 2 ft. long was fitted so that it was in contact with the grid and in mesh with it. The observed values of U/u' are shown in Fig. 3; in this diagram $u' = \sqrt{\overline{u^2}}$ and x is the distance in feet of the observation point from the screen.

It will be seen that the points lie very truly on a straight line. For this reason if the turbulence is "self-preserving" α must in this case be $1/_8$. Using this value for α, the author has solved Eq. (8) in series. The results are shown in Fig. 4. The parabola which touches the curve at the vertex (shown dotted), meets with the axis at $X = \sqrt{10}$. This point must correspond with $r = \sqrt{2\lambda}$ and λ is found either by measuring the curvature of the observed R_1 curve at the vertex or better by using Eq. (7) which can be written

[2] Proceedings of the Royal Society, Vol. 157, page 540, 1936.

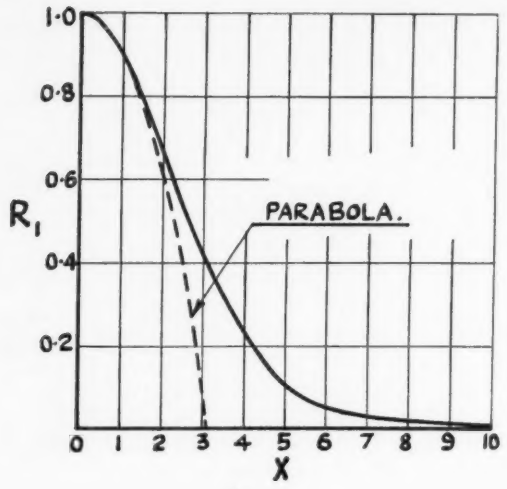

FIG. 4.

$$\frac{u'}{U}\frac{d}{dx}\left(\frac{U}{u'}\right) = \frac{5\nu}{U\lambda^2} \qquad (11)$$

At 6 ft. 10 in. from the grid $U/u' = 33$ and $\frac{d}{dx}\left(\frac{U}{u'}\right) = 0.1478$ cm.$^{-1}$ (see Fig. 3). Hence from Eq. (11) $U\lambda^2 = 156.4$ cm.^{3} sec.$^{-1}$. At $U = 35$ ft. per sec. this gives $\lambda = 0.38$ cm. and at $U = 15$ ft. per sec., $\lambda = 0.58$ cm.

In order to compare the calculated R_1 curve with the measured values of R_1 shown in Fig. 1, it is necessary to take the scale of the calculated curve so that $X = \sqrt{10}$ corresponds with $r = \sqrt{2\lambda} = 0.54$ cm. at $U = 35$ ft. per sec., or $r = 0.82$ cm. at $U = 15$ ft. per sec. Taking the latter case it will be seen that $X = 1$ in the curve of Fig. 4 corresponds with $r = 0.102$ in. in Fig. 1. The calculated $R_1(r)$ curve so produced is shown in Fig. 1.

It will be seen that the observed $R_1(r)$ curve is very different indeed from that calculated on the assumption that turbulence is "self-preserving" and that the $R_1(r)$ curve preserves its shape. The difference would have been still greater if the comparison had been made at $U = 35$ ft. per sec.

VON KÁRMÁN'S THEORY OF DECAY OF TURBULENCE CONTRASTED WITH THAT OF THE AUTHOR

In his discussion of the decay of isotropic turbulence in a wind tunnel, von Kármán arrives at Eq. (10), which, as he points out, is identical in one particular case with the linear law of increase in U/u', which the author had previously obtained making a different assumption. He states, "*this general theory includes Taylor's as a special case.*" The author does not agree with this view because von Kármán's theory is based on the assumption that the $R_1(r)$ curve preserves its shape so that its spread increases as λ increases. Thus, if $L_1 = \int_0^\infty R_1 dr$, von Kármán assumes that λ/L_1 is constant whereas the author's assumption is that L_1 remains constant but that λ is related to the linear scale of the grid which produces the turbulence by a relationship which is of the same form as that von Kármán, himself, uses later in another connection. This relationship in his notation[3] is $\frac{q\lambda^2}{\nu L} \sim 1$ or in the author's $\frac{\lambda^2 u'}{\nu M} = A^2$, where A is a constant and M is the mesh length of the grid. The essential feature of the author's assumption is that the scale of the turbulence produced by the grid is preserved down the stream. Von Kármán's assumption, that λ/L_1 is constant, means that L_1 increases down the tunnel. A crucial experiment can be made in a wind tunnel to test the truths of these assumptions. It is clear that the author's linear law of decay can only be expected to apply when a very definite scale can be ascribed to the turbulence. If the air in a wind stream has already a small amount of large scale turbulence when it strikes a screen of small mesh the linear law could not be expected to apply. If, for instance, the two types of turbulence could be superposed, each obeying its own linear law of decay, the result would be

$$\frac{\overline{u^2}}{U^2} = \left(\frac{1}{A_1 + \frac{Dx}{M_1}}\right)^2 + \left(\frac{1}{A_2 + \frac{Dx}{M_2}}\right)^2 \qquad (12)$$

If M_1 is small compared with M_2, and A_1 is small compared with A_2, it will be seen that near $x = 0$ the turbulence obeys the linear law corresponding with the small mesh, *i.e.*, $U/u' = A_1 + (Dx/M_1)$ while when x is large it approaches the linear law for large mesh, namely $U/u' = A_2 + (Dx/M_2)$.

For this reason the author realized that to obtain the linear law experimentally one must ensure that no turbulence larger than that corresponding with some definite mesh length M shall pass through the grid. Turbulence of smaller mesh length than M will die out more quickly than those of mesh length M. If therefore the author's theory is correct, there are two obvious ways in which turbulence with a linear law of decay might be obtained practically. A regular grid can be set upon a wind stream which is initially free from turbulence, or a long honeycomb can be set up, the turbulence-producing mesh being put in contact with the ends of the honeycomb cells so that the mesh registers with them. The values of U/u' shown in Fig. 3 were obtained with the latter arrangement. It will be seen that the linear law of decay is in fact attained.

It is clear that the author's assumption that the scale of the turbulence does not vary with time is not

[3] Th. von Kármán, *The Fundamentals of the Statistical Theory of Turbulence*, Journal of the Aeronautical Sciences, Vol. 4, No. 4, page 135, February, 1937.

consistent with Eq. (3), but it seems that when the $R_1(r)$ curve is of the type which is observed behind a grid in a wind tunnel, Eq. (3) predicts something which is certainly not in accordance with observation. When the $R_1(r)$ curve is measured at a fixed section with varying wind-tunnel speeds, it is found to be practically invariable, except that the curvature at $r = 0$ increases as the wind speed increases. Writing Eq. (3) in the form

$$\frac{\partial R_1}{\partial t} = 2\nu\left(\frac{\partial^2 R_1}{\partial r^2} + \frac{4}{r}\frac{\partial R_1}{\partial r} + \frac{5}{\lambda^2}R_1\right) \tag{13}$$

it will be seen that when the $R_1(r)$ curve is like that shown in Fig. 1 the terms $\frac{\partial^2 R_1}{\partial r^2}$ and $\frac{4}{r}\frac{\partial R_1}{\partial r}$ are only comparable with $\frac{5}{\lambda^2}R_1$ in a small range near $r = 0$. Outside this range Eq. (7) may be written $\frac{\partial R}{\partial t} = \frac{10\nu}{\lambda^2}R_1$; and from Eq. (7) they will be seen to be

$$\frac{1}{R_1}\frac{\partial R_1}{\partial t} = \frac{-1}{\overline{u^2}}\cdot\frac{\partial \overline{u^2}}{\partial t}$$

so that for a fixed value of r,

$$R_1\overline{u^2} = \text{constant} \tag{14}$$

In the measurements made at the National Physical Laboratory $\overline{u^2}$ varied in the ratio 6.7:1 (see Fig. 3), but the values of R_1 at $r = 2$ in. varied by only a few percent over the whole range, instead of increasing 6.7 times as predicted by Eq. (14).

Comparison of Ideas Underlying von Kármán's and the Author's Assumptions

It seems that the essential contrast between von Kármán's and the author's assumptions lies in the difference between their views as to the significance of the "inertia" terms in the mechanism of turbulent motion. Von Kármán considers that they have no effect, at any rate in the problems with which he is concerned. In the author's view they represent the fundamental mechanical cause which controls the dissipation of energy in turbulent motion.

The idea the author has in mind is that the turbulence in a wind tunnel is found to be diffusive, *i.e.*, the average distance between pairs of particles A and B continually increases. Suppose that a random vorticity is set up in a fluid and that this gives rise to turbulent motion which proves to be diffusive. Choose particles A and B a short distance d_0 apart on a vortex line where the initial vorticity is ω_0. If the viscosity is very small the vortex line will remain a vortex line and the vorticity will change in accordance with the law $\omega^2 = d^2\omega_0^2/d_0^2$ where d is the distance apart at any time. Since the motion is diffusive, the average value of d^2/d_0^2 will continually increase so that the average value of ω^2 will continually increase. This process may be expected to continue until ω becomes so large that the vorticity is destroyed by viscosity faster than it is produced by the stretching of vortex filaments. This process can only be represented by the "inertia" terms in the equation of motion.

It is clear that von Kármán does not consider that this process has any essential bearing on the mechanism of turbulent motion for he writes "*It will be assumed in this paper that the expression* $\Sigma_i\Sigma_k\omega_i\omega_k\frac{du_i}{dx_k}$ *is zero.*" He points out that if ω_3 is the vorticity when the vortex line coincides with the axis x_3 he is assuming that the mean value of $\omega_3^2\frac{\partial u_3}{\partial x_3}$ vanishes.

It will be seen that in the author's view if a turbulent motion is set up there will be a strong correlation between ω_3^2 and $\frac{\partial u_3}{\partial x_3}$ so that $\omega_3^2\frac{\partial u_3}{\partial x_3}$ is not equal to zero.

In a recent paper[4] A. E. Green and the author have attempted to analyze in detail the idea outlined above, starting with a special type of motion—not a turbulent motion. Attempts were made to trace the increase with time of the mean value of the square of the vorticity, when the special type of motion represented by

$$\begin{aligned} u &= A\cos ax \sin by \sin cz \\ v &= B\sin ax \cos by \sin cz \\ w &= C\sin ax \sin by \cos cz \end{aligned} \tag{15}$$

is set up at time $t = 0$. If A and B are suitably chosen it is found that the rate of dissipation of energy increases with time owing to the increase of vorticity. The analysis is very difficult, but by defining a Reynolds Number of turbulence $R = A/a\nu$, where A and a have the meaning given them in Eq. (15), it was found that after a time the rate of dissipation rises to a maximum and then begins to decrease owing to decrease in the energy of the turbulence. Unfortunately the range of R and t in which the approximations could be considered as reasonably valid was not sufficiently great, but the maximum dissipation was definitely comparable with that given by the author's formula $\lambda/M = 2\sqrt{\nu/Mu'}$ when the analogy between $1/a$ and M had been taken into account.

In conclusion, the author wishes to thank L. F. G. Simmons for his permission to publish his experimental results.

[4] G. I. Taylor and A. E. Green, *Mechanism of the Production of Small Eddies from Large Ones*, Proceedings of the Royal Society, A, Vol. 158, page 499.

Aircraft Vibration Flight Testing

GEORGE P. BENTLEY, *Massachusetts Institute of Technology*

Presented at the Instruments, Radio and Radio Meteorograph Session, Fifth Annual Meeting, I. Ae. S. January 27, 1937

Introduction

THE study of aircraft vibration which is described in this paper is part of a joint research program being carried out by the Bureau of Aeronautics of the U. S. Navy and the Massachusetts Institute of Technology. The work was performed at the Naval Aircraft Factory by the author with the assistance of Messrs. Wiese and Pearson of the Naval Engineering staff, and the cooperation of C. S. Draper and E. S. Taylor of M.I.T.

All experimental data was taken with the electrical vibration recording equipment developed as part of an M.I.T.-Navy research program. This apparatus has already been described in two papers.[1,2]

Aircraft Installation

A typical flight test installation of the equipment is shown in Fig. 1. To make a thorough, factual study of the vibration, pick-up units were secured at various places in the airplane with the amplifying and recording equipment located in the rear cockpit. These pick-up locations, as shown in Fig. 1 and in the engine mount sketch of Fig. 2, permit the following components of vibration to be measured:

Complete Engine Motion	(1) Vertical engine vibration; proportional to the mean motion of units 1 and 2.
	(2) Fore and aft engine vibration; mean of the motion of units 3 and 4.
	(3) Lateral engine vibration; mean of the motion of units 5 and 6.
	(4) Torsional crankcase vibration about span axis; proportional to the difference of motion between units 1 and 2.
	(5) Torsional crankcase vibration about vertical axis; proportional to the difference of motion between 3 and 4.
	(6) Torsional crankcase vibration about thrust axis; proportional to the difference of motion between units 5 and 6.
Crankshaft Vibration	(7) Torsional vibration of engine crankshaft; unit 7.
Structural Vibration	(8) Vertical vibration at cabane struts and firewall; motion of units 8 and 9.
	(9) Torsional vibration of firewall sections; proportional to difference of motion between units 8 and 9.
	(10) Vertical shear distortion in engine mount structure (approximate); motions of units 1 and 2 combined with units 8 and 9.
	(11) Torsional distortion in engine mount structure (approximate); motion of units 5 and 6 combined with units 8 and 9.
	(12) Vertical vibration of tail assembly at root of stabilizer; unit 11.
	(13) Vertical vibration at interplane strut; unit 10.

An installation practice that has been found satisfactory is shown in Fig. 3. The pick-up units are either bolted to the structure or fastened securely with Wraplock, and the individual lead wires carried to binding posts on a conveniently situated distribution panel, E. The panel may be secured to a motor mount member, as in Fig. 3. Securing pick-up units with Wraplock must be done carefully if the higher frequency motions are not to be lost due to slippage.

The binding posts on the distribution panel, E, are wired to a multi-wire receptacle, A (Fig. 3). A multi-wire cable serves to transfer the pick-up impulses aft to the control panel, B, (Figs. 1 and 4) in the observer's cockpit. Tap-switch, C, is wired so that each tap position connects a pair of pick-up units to their assigned amplifier channels through leads, D.

The amplifier equipment, suspended from the structure aft of the observer's seat, is shown in Fig. 5. The recorder is located to the left of the control panel in the compartment provided for the ship's radio equipment (Fig. 4).

[1] C. S. Draper and G. P. Bentley, *Measurement of Aircraft Vibration During Flight*, Journal of the Aeronautical Sciences, Vol. 3, No. 4, February, 1936.

[2] C. S. Draper, G. P. Bentley and H. H. Willis, *The M.I.T.-Sperry Apparatus for Measuring Vibration*, Journal of the Aeronautical Sciences, Vol. 4, No. 7, May, 1937.

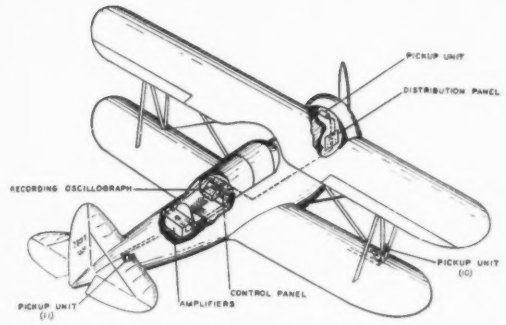

FIG. 1. Installation of equipment for measurement of vibration in flight.

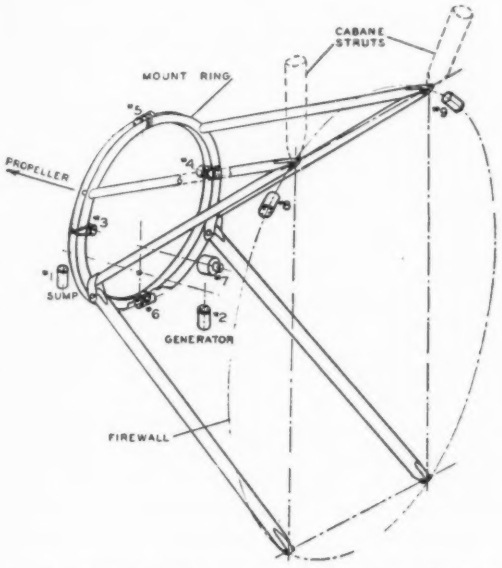

FIG. 2. Engine mount structure of test airplane showing pick-up unit locations.

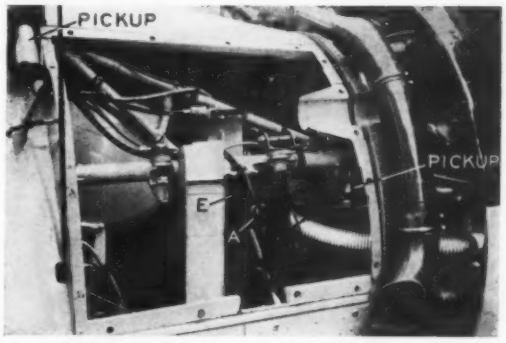

FIG. 3. Pick-up unit installation in airplane showing distribution panel.

FIG. 4. Installation of vibration recorder and control panel in observer's cockpit.

For phasing the records with respect to the engine cycle, the shield was removed from the master cylinder spark lead; a wire, wrapped around the lead three or four turns, and coupled to one of the amplifier channels will leave a distinctive "kick" on the record trace each time the master cylinder fires (see Fig. 8).

RECORDING PROCEDURE

The high sensitivity available in the electrical type of equipment leads to a temptation to adjust the sensitivity for each record until a large amplitude trace is obtained on the film. For most test work, however, this is not only unnecessary but undesirable. The sensitivity is best adjusted to give a trace that fully traverses the film under conditions of maximum vibration, and then left at that sensitivity for all other records. It may become necessary to change the sensitivity between crankshaft torsional vibration and linear vibration records due to the entirely different types of motion and pick-up. It was found that the full-power climb to the test altitude provided an excellent opportunity for sensitivity adjustment, vibration conditions usually being very near the peak.

Once the airplane and engine conditions are stabilized, the recording procedure is a simple routine: (1) set the tap-switch, (2) take the record, and (3) note pertinent data against the record number. The use of eleven pick-up units necessitates six tap-switch positions, or six records at each engine speed. All six records can be taken within a period of 25 to 30 seconds of engine operation, insuring very close to identical operating conditions for all records. Since a total of about 50 records is the maximum available on the 100 feet of film carried in the recorder, six records at each of eight engine speeds can be taken. The total flight time for such a series is about 12 minutes.

RECORD ANALYSIS AND RESULTS

In Fig. 6 record 6a reproduces an interval of four engine revolutions from the traces of pick-up units 5 and 6 at 1800 r.p.m., the positive directions of motion

FIG. 5. Amplifier installation in rear cockpit of test airplane.

shown in the figure corresponding to a motion of the pick-up toward the right wing tip.

The "kick" left on the record trace by the spark pick-up arrangement is also shown. Since the spark advance was 25° the true crankshaft angle may be plotted along the curve abscissa.

The first step in the analysis of a record of this type is the separation of the two traces into the torsional and translational components of the motion of the engine structure to which the pick-up units were attached. Adopting the notation shown on record 6a, the instantaneous torsional and translational displacements at a point half-way between the pick-up units may be found by addition and subtraction:

$$X_{(\text{translation})} = \frac{xK_x + yK_y}{2} \text{ inches}$$

$$\theta_{(\text{torsion})} = \frac{xK_x - yK_y}{d} \text{ radians}$$

where K_x, K_y = overall calibration constants of the pick-up units and amplifying-recording equipment, and d = distance between the pick-up units in inches.

Any axes of reference parallel to the edge of the film may be selected for measurement of x, y; changes in these axes result only in a greater or lesser distance between the true equilibrium axes for X, θ and the parallel reference axes used in the construction of the curves of X, θ. Application of this method to record 6a produces the results 6b and 6c.

Further record analysis follows the conventional methods for breaking down the curves of 6b and 6c into their harmonic components, in order to obtain the amplitude of each frequency present. It has been found advisable to carry this analysis through on a record section at least four engine revolutions in length

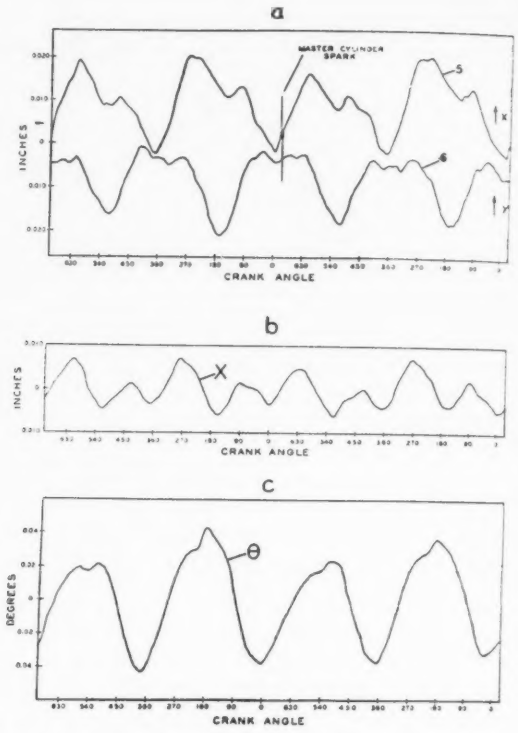

FIG. 6. Separation of record traces into curves of torsional and translational motion.

to be sure of including sub-harmonics of engine revolution speed. In some cases even four revolutions are insufficient; the idling "lope" of many radial engines, for instance, is cyclic once every four revolutions, and traces of this frequency have been found even at high engine operating speeds.

Analysis of the records from pick-up units 5 and 6 for all engine speeds shows vibration throughout the engine range of two types: (1) a translational motion of the engine from side to side at twice engine revolution frequency, and (2) a torsional motion of the engine about the thrust axis at engine revolution frequency. The effect of engine speed on the amplitude of these two vibration components is shown in the curves of Fig. 7. The resonant peak amplitude on the torsional vibration curve was located by readings of the recorder meters as the engine passed through the resonant condition. The amplitude of engine motion, in torsion at the resonant speed of 1550 r.p.m. with the rigid engine mount used on the airplane, is approximately ten times greater than if the engine were restrained to a much lesser degree by a flexible mounting structure. Such violent engine motion leads to vibration at this frequency throughout the airplane and the faulty engine mount design is doubtless responsible for the major part of the airplane roughness.

Other components of the engine vibration may be analyzed as outlined above. Analysis of records such as Fig. 8 (a and b) showing respectively the ver-

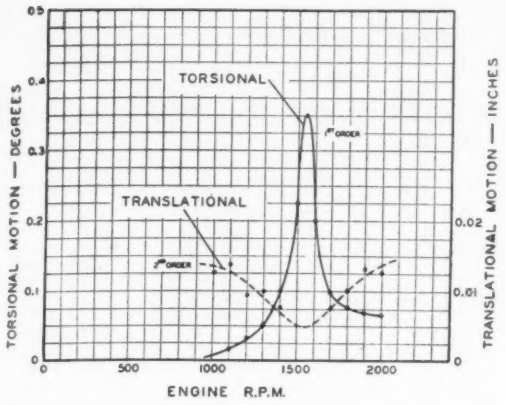

FIG. 7. Torsional vibration of engine crankcase about thrust axis, and translational span-wise vibration of engine crankcase in flight. (Nine cylinder radial engine.)

tical motion at the tail structure and interplane strut for one engine speed requires no separation into components, but merely harmonic analysis. Behavior of the tail and wing structures throughout the engine operating range is shown in Fig. 9.

That the pronounced engine vibration shakes the entire airplane is evidenced by the resonant peaks of the first order at 1550 r.p.m. in the cases of both interplane strut and stabilizer vibration. There is also a natural frequency in the stabilizer system of approximately 4800 cycles per minute. This is excited to a small degree at low engine speeds by the fourth order vibration from the engine; at higher speeds the more powerful second order engine vibration causes much larger stabilizer motion. Some of the second order engine motion is also felt at the interplane strut.

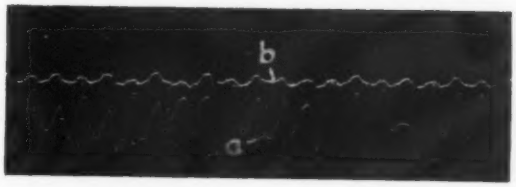

FIG. 8. Vertical vibration of stabilizer (a) and interplane strut (b) of test airplane. Note spark indication in (b).

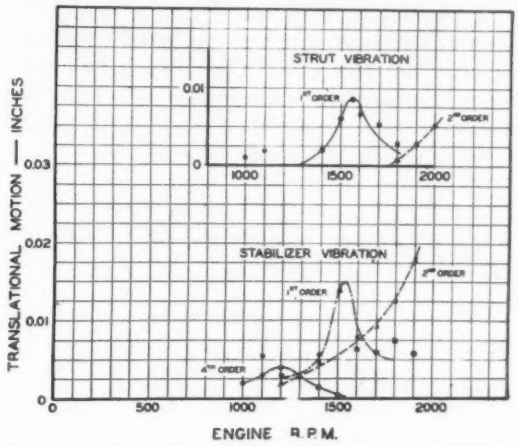

FIG. 9. Vertical vibration of interplane strut and stabilizer root in flight.

The results here briefly described are but a small part of the story told by one set of records. It is hoped that the passing on of the experience gained in these tests will assist in vibration testing and analysis. With the vibration measuring equipment for flight work now available, the solution of individual vibration problems, rather than measurement difficulties, can claim the attention of engineers.

Errata

The following corrected mathematical expression corrects an error inadvertently made in the printing of Dr. Hugh L. Dryden's article on *"The Theory of Isotropic Turbulence,"* on page 277 of the May, 1937 issue, Vol. 4, No. 7.

$$E_\lambda = K \frac{E}{\lambda_1} \left(\frac{\lambda}{\lambda_1}\right)^{-n} e^{-\frac{k\lambda_1^2}{\lambda^2}} \qquad (10)$$

Stress Distribution in Stiffened Panels Under Compression

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Presented at the Structural Problems in Aircraft Design Session, Fifth Annual Meeting, I. Ae. S. January 27, 1937

Introduction

INASMUCH as it is one of the basic elements of monocoque construction, the allowable load and the stress distribution of a stiffened thin sheet panel under compression is of great importance to the designer. The use of an effective width of sheet acting with the stiffener has found favor with designers and this paper is primarily concerned with methods of calculating this effective width, not only at the ultimate strength of the panel, but also at lower loads.

First Theory

In 1933 a program of experimental research was started by the author, the purpose of this program being to determine the allowable loads that could be carried by a simply supported, flat thin sheet metal panel, when subjected to a compressive load parallel to its own plane. This work was a continuation and extension of a similar investigation carried out in the Bureau of Standards by Schuman and Back.[1] Simultaneously with the experimental program, theoretical studies were made, using a modified small deflection theory, in order to determine, if possible, the parameters which affected the problem.

For this preliminary theoretical investigation, it was assumed that the stress distribution across the loaded edges could be divided into two portions. First, it was assumed that there was an effective width "w_e" on both sides of the sheet, adjacent to the supported edges, which at failure carried the yield point stress of the material, σ_y. Second, that the center portion of the panel carried a uniformly distributed stress equal to the buckling stress of the panel (see Fig. 1). The regions near the edges were calculated by the stability theory of Bryan [2,3] and, by assuming that the stress at buckling of this region was equal to the yield point of the material, the effective width could be determined. Then, by summing the loads carried by these two portions of the loaded edges, the total load carried by the panel was obtained.

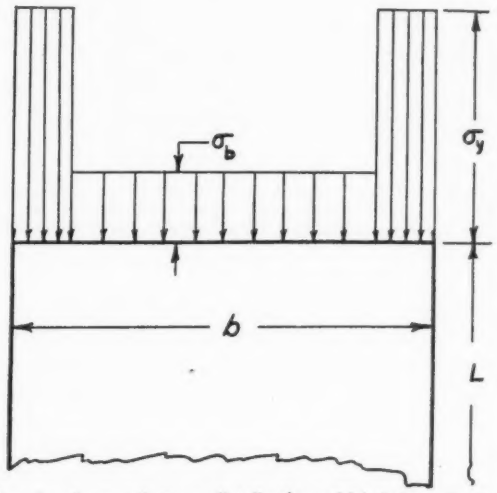


FIG. 1. Assumed stress distribution which led to the important parameter λ.

Type of Equation and Experimental Results

From the above treatment it was found that the total load that could be carried by any simply supported panel could be given by an equation of the form

$$P = C\sqrt{E\sigma_y}t^2 \qquad (1)$$

where E = Young's Modulus of the material
t = the thickness of the panel
σ_y = the yield point of the material

The constant C was indicated by the theory to be a function of the dimensionless parameter

$$\lambda = \sqrt{\frac{E}{\sigma_y}}\,\frac{t}{b} \qquad (2)$$

where b is the width of the panel. The actual relationship between C and λ was determined by testing a large number of panels, of different materials and different dimensions, to failure in a special testing machine in the aeronautical structures laboratory of the California Institute of Technology. From these tests a curve of C *vs.* λ was drawn which is shown as curve A in Fig. 2.

As would be expected from the crudeness of the basic assumptions, the above theoretical treatment gave values for the total load which were not in good agreement with the experimentally obtained values. However, the study did yield the important parameter λ

[1] Louis Schuman and Goldie Back, *Strength of Rectangular Flat Plates Under Edge Compression*, N.A.C.A. Technical Report No. 356, Washington, D. C., 1930.

[2] G. H. Bryan, *On the Stability of a Plane Under Thrusts in its own Plane with Application to the Buckling of Sides of a Ship*. Proceedings of the London Mathematical Society, Vol. 22, 1891.

[3] Th. von Kármán, Ernest E. Sechler, and L. H. Donnell, *The Strength of Thin Plates in Compression*, Applied Mechanics Transactions of the A.S.M.E., June, 1932.

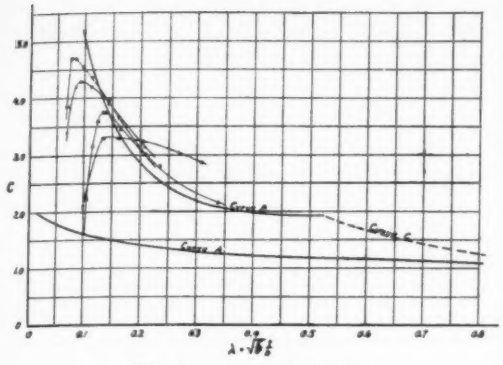


FIG. 2. Curves of C *vs.* λ.

and the dependance of C on λ could be determined experimentally. It is interesting to note that other investigators,[4,5] using various assumptions as to wave form and load distribution, all met with essentially the same results. Their theoretical values of the total load do not give good agreement with the failing loads actually obtained on the specimens, but their expressions for this value can all be put into the form

$$P = C\sqrt{E\sigma_y}\, t^2$$

where C is a function of λ.

THE EFFECTIVE WIDTH

The effective width, w_e, is found by the relationship

$$P = C\sqrt{E\sigma_y}t^2 = 2w_e t\sigma_y$$

which gives

$$w_e = \frac{C}{2}\sqrt{\frac{E}{\sigma_y}}\, t \tag{3}$$

or, in terms of λ

$$w_e = Cb\lambda/2 \tag{4}$$

This can be put into the form

$$w_e/b = C\lambda/2 \tag{5}$$

and, using the experimental values of C *vs.* λ from curve A, Fig. 2, a curve is obtained as shown as curve A, Fig. 3.

APPLICATION TO STIFFENED PANELS

In the case of flat sheet panels combined with stiffeners, the principle of an effective width is also applied. That is, it is assumed that a certain width of the flat sheet is acting under the same stress as that in the stiffener, the stiffener and this effective width then acting as a column under uniform stress to resist the applied compressive load.

[4] H. L. Cox, *Buckling of Thin Plates in Compression*, British R. & M. No. 1554.

[5] M. Yamamoto and K. Kondo, *Buckling and Failure of Thin Rectangular Plates in Compression*, Tokyo Imperial University Report No. 119.

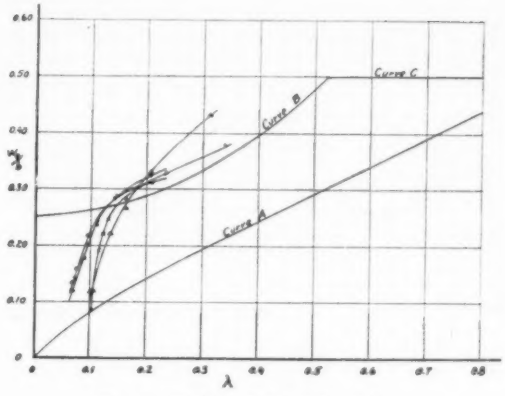


FIG. 3. Values of the ratio w_e/b.

If it could be assumed that the stress pattern throughout the sheet remained of the same form for all loads up to failure, it would be possible to use the experimental failure curve of Fig. 2 to determine the effective width acting with the stiffener. If σ_s is the stress in the stiffener, then the load carried in the sheet would be (under the above assumption)

$$P_{sh} = C\sqrt{E\sigma_s}t^2 \tag{6}$$

where C would be determined from Curve A, Fig. 2 using

$$\lambda = \sqrt{\frac{E}{\sigma_s}}\,\frac{t}{b} \tag{7}$$

and the effective width would be

$$w_e = \frac{C}{2}\sqrt{\frac{E}{\sigma_s}}\, t \tag{8}$$

as shown by curve A, Fig. 3.

However, experiments on stiffened panels showed that the effective width calculated in this manner was too small, especially for low loads, and that the above method only checked the test results at failure. Also, experiments on flat panels without stiffeners indicated that the stress pattern was probably changing during the loading inasmuch as a panel that started by buckling in one half-wave in the direction of the load would, at higher loads, have possibly one half-wave in the center of the panel, three half-waves some distance from the edge, and five half-waves very close to the edge. Deflections normal to the plane of the sheet also became so large that it was evident that bending stresses must play some part in the mechanism of failure.

DETERMINATION OF ACTUAL COMPRESSIVE STRESS DISTRIBUTION

In order to more closely determine the stress conditions in the sheet an attempt was made to experimentally determine the compressive stress distribution in a stiffened panel. The panel tested had one stiffener in the center, and the edges of the sheet were supported in vee grooves. Stress readings were taken on both

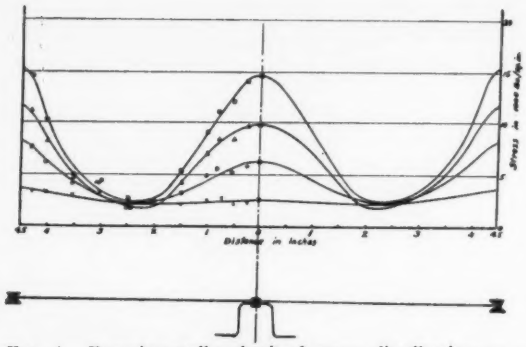


FIG. 4. Experimentally obtained stress distribution on a stiffened panel.

sides of the sheet which made possible the separation of the bending and the direct compression stress. The curves obtained are shown in Fig. 4.

From these experiments, it was found that the compressive stress distribution in a sheet connected to stiffeners could be given by an equation of the form

$$\sigma_c = \frac{1}{2}\left[\sigma_s + \sigma_b + (\sigma_s - \sigma_b)\cos\frac{2\pi x}{b}\right] \qquad (9)$$

where

σ_b = the buckling stress of the sheet = $3.62\,E\left(\frac{t}{b}\right)^2$

σ_s = the stress in the stiffener

For an unstiffened sheet supported in vee grooves, the compressive stress distribution is given by the equation

$$\sigma_c' = \sigma_s - (\sigma_s - \sigma_b)\sin\frac{\pi x}{b} \qquad (10)$$

These curves are shown in Figs. 5 and 6 and the experimental points are shown plotted, indicating a good agreement with the above equations.

Effective Width below Failure

If the equation given above (Eq. (9)) is used for the compressive stress in the sheet for a stiffened panel, it is seen that the total compression load carried by the sheet is equal to

$$P_{sh} = t\int_0^b \sigma_c dx = t\int_0^b \frac{1}{2}\left[\sigma_s + \sigma_b + (\sigma_s - \sigma_b)\cos\frac{2\pi x}{b}\right]dx = tb(\sigma_s + \sigma_b)/2 \qquad (11)$$

Putting this into the form of Eq. (6)

$$P_{sh} = C\sqrt{E\sigma_s}t^2 = tb(\sigma_s + \sigma_b)/2$$

and, substituting in the value for σ_b,

$$C = \frac{1}{2}\frac{b}{t}\sqrt{\frac{\sigma_s}{E}} + 1.81\sqrt{\frac{E}{\sigma_s}}\frac{t}{b}$$
$$= 0.50/\lambda + 1.81\lambda \qquad (12)$$

This value of C is shown as curve B in Fig. 2. It is limited on the right by the value of C corresponding to a uniform distribution of stress across the sheet, in which case it can be shown that

$$C = 1/\lambda \qquad (13)$$

This is shown as curve C in Fig. 2.

The effective width can also be calculated, giving

$$P_{sh} = 2w_e t\sigma_s = tb(\sigma_s + \sigma_b)/2$$

$$w_e = \frac{b}{4}\left(1 + \frac{\sigma_b}{\sigma_s}\right)$$

and, substituting in the value σ_b,

$$w_e = b[0.25 + 0.91\,\lambda^2] \qquad (14)$$

$$w_e/b = (0.25 + 0.91\,\lambda^2) \qquad (15)$$

This is shown plotted as curve B in Fig. 3, and again it is limited by curve C corresponding to the uniform stress distribution.

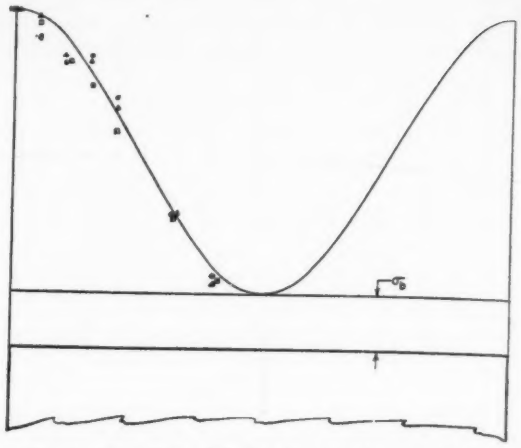


FIG. 5. Plot of Eq. (9), showing experimental check.

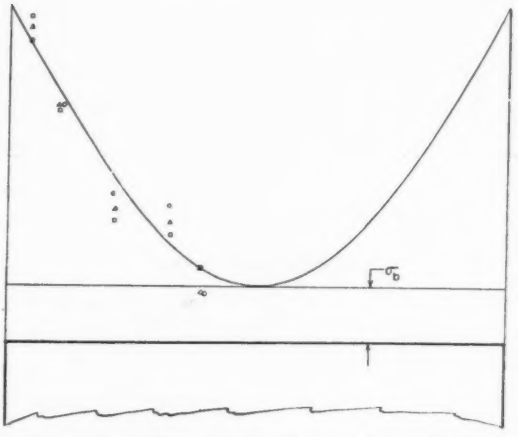


FIG. 6. Plot of Eq. (10), showing experimental check.

Experimental Results from Stiffened Test Panels

A large number of stiffened panels have been tested under compression by the structures group at GALCIT, and a group of these panels has been used to check

the above formulas for C and w_e. These panels were tested as flat end columns under compression in standard testing machines and were taken up to failure. Extensometers were mounted on the stiffeners which gave the value of σ_s. Then, knowing the area of the stiffeners, the amount of the compression carried by the stiffeners only could be calculated as

$$P_s = A_s\sigma_s$$

The amount of compression load carried by the sheet is obviously given by

$$P_{sh} = P_T - P_s$$

where P_T is the total load carried by the entire panel. From the value of P_{sh} and σ_s and the known dimensions of the plate, it was possible to calculate C and w_e from Eqs. (12) and (14). This has been done for the panels tested and a few of the experimental curves are shown in Figs. 2 and 3.

A study of the results obtained experimentally on stiffened panels, brings to light three very interesting items. They will first be enumerated and then discussed individually in more detail. These items are:

(1) The experimental values of w_e are large at low values of λ, and are given closely but conservatively by Eq. (14). The same is true of the value of the constant C.

(2) At some value of λ, the effective width and the constant C decrease rapidly in value, tending toward, and at times reaching, the values given by the curve obtained by testing flat sheets to failure.

(3) That there are three stress regimes during the loading of a stiffened panel to failure, namely,

(a) A region at low loads in which the values of C and w_e are high and which corresponds to a compressive stress distribution as given by (Eq.) 9.

(b) A transition region starting at some critical value of the stiffener stress.

(c) A point which indicates the maximum allowable load that it is possible for a thin sheet panel to carry. This point, and the curves of C and w_e *vs.* λ have not yet been satisfactorily obtained theoretically, but have been obtained by a large number of tests on thin sheet panels tested to failure.

The first item indicates that the assumed stress distribution is reasonably correct for stiffened panels of a size customarily used in aircraft construction. Also that Eqs. (14) and (15) should be used to determine the effective widths of stiffened panels up to some critical stiffener stress.

The critical value of λ, below which, the values of C and w_e rapidly decrease, seems to be determined by one of two items. First, the stiffener may reach a critical stress from the standpoint of the material of the sheet, *i.e.*, the yield point or proportional limit. The test results show that this value is very near to the proportional limit, or about 20,000 lbs. per sq. in. for all of the aluminum alloys tested. The second item which may determine this critical value is the stiffener stress at which buckling occurs between rivets. This stress has been calculated by Howland[6] and where the value of the stiffener stress for buckling between rivets is less than the proportional limit, the tests show that the buckling stress governs.

Preliminary theoretical investigations of the actual stresses in the sheet indicate that the entrance into the transition region may also be influenced by the combined stresses; composed of a combination of direct stresses and bending stresses due to the sheet being in the wave state. In order to fully analyze this region, it will be necessary to consider the rather complicated multi-wave pattern which is taken by the sheet and which pattern varies as the load is increased. Work is being carried on in this field at the present time at the California Institute and in other laboratories.

The fact that the C and w_e values do not drop entirely to the failure curve only means that the combined column (stiffener plus effective widths) failed in some manner before the stiffener stress corresponding to sheet failure had been reached. This failure point will depend upon the properties of the stiffener, the effect of the attached sheet on these properties, the end fixity, and the eccentricity of the combined column. However, this is a completely separate problem and is too involved to be discussed in this paper.

The above study of the stress distribution in stiffened panels now makes it possible to obtain an accurate picture of the actual compressive stress distribution across the sheet material. For stress analysis purposes it enables the designer to determine the amount of sheet material which can be considered to be acting with the stiffener at loads before failure. This item is important for the determination of the stress values and distributions under applied loads. The value of λ at which this distribution no longer holds may be determined from the proportional limit of the material or from the stress for buckling between rivets. The point on the failure curve corresponding to the particular sheet panel may be found from Eq. (2), and it is suggested that the curve in the transition region be considered a straight line until a more accurate determination of its shape has been made. With this complete knowledge of the effective width, the designer can determine the amount of load carried by a panel for any given stiffener stress by the following simple equation

$$P = n(A_s + 2w_e t)\sigma_s$$

where

n = number of stiffeners
A_s = area of one stiffener
w_e = effective width at the stiffener stress σ_s
t = thickness of the sheet material

[6] W. Lavern Howland, *Effect of Rivet Spacing on Stiffened Thin Sheet Under Compression*, Journal of the Aeronautical Sciences, Vol. 3, No. 12, October, 1936, pages 434–439.

The Graphical Solution of Stability Problems

R. K. MUELLER, *Glenn L. Martin Company*

Presented at the Airplane Stability and Performance Session, Fifth Annual Meeting, I. Ae. S. January 29, 1937

Summary

IN THIS paper certain graphical conventions and their application to the solution of problems in stability and vibration are described. While the method is essentially a trial and error one, it suggests in many cases analytical approximations for frequency and effective damping which will be quite acceptable in practice, particularly since the degree of error can be estimated.

This is especially true of the longitudinal motion of the airplane, a typical example of which is worked out for demonstration purposes. Analytical expressions for the period and damping are derived from graphical reasoning and shown to give nearly the same result as the approximate factorization of the biquadratic usually resorted to. The damping formula is also compared with one given by Gates in R. and M. 1118 and shown to be equivalent except for one additional term in Gates' formula, the addition of which appears to constitute an error.

Finally, on the basis of the analytical approximations developed, a system of plotting the longitudinal stability characteristics of an airplane in all flight conditions is presented.

In a later article the result of applying this method to the lateral and directional motion of the airplane and to various types of automatic stabilization, will be described.

Graphical Conventions

Electrical engineers have made use of "vector" diagrams to represent alternating currents and voltages for many years. Perhaps because this science has been so long concerned with a kind of vibration or alternation in the sphere of communication as well as power transmission, the advantages of certain graphical conventions have been more widely recognized and applied than in other fields where they are potentially useful.

The representation of a quantity varying harmonically with the time with no average increase or decrease in amplitude is well known. Fig. 1a shows that if a point moves with uniform angular velocity on a circle of radius x_0, the length of the projection of its radius vector on any line passing through the center is

$$x = x_0 \cos(\omega t + \phi)$$

where ϕ is included so as not to restrict the line on which the projection is made. It is necessary to establish a correspondence between units of the quantity and of length as well as a sign sense of length, but these are arbitrary. The derivative of x with respect to t taken in the usual manner is

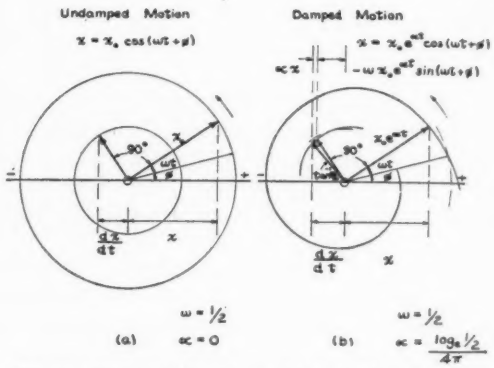


FIG. 1. Harmonic functions of time and derivatives.

$$\frac{dx}{dt} = -\omega x_0 \sin(\omega t + \phi)$$
$$= \omega \cos(\omega t + \phi + 90°)]$$

This, clearly, may be expressed as the projection of a second vector 90° ahead of the first and in length multiplied by ω. By similar reasoning higher derivatives may be represented by additional vectors advanced 90° and multiplied by ω as many times as the order of the derivative. Integrations are the converse, angular changes being back and ω a divisor instead of multiplier.

If the average amplitude of the quantity is increasing or decaying exponentially with the time, it may be expressed as shown in Fig. 1b.

$$x = x_0 e^{\alpha t} \cos(\omega t + \phi)$$

The effect of the exponential factor is simply to multiply the length of the vector. Its angular position is unchanged. If the derivative is again taken analytically

$$\frac{dx}{dt} = \alpha x_0 e^{\alpha t} \cos(\omega t + \phi) - \omega x_0 e^{\alpha t} \sin(\omega t + \phi)$$
$$= x_0 e^{\alpha t}[\alpha \cos(\omega t + \phi) + \omega \cos(\omega t + \phi + 90°)]$$

This consists of two terms, the second the same as before with a factor $e^{\alpha t}$ and the first equal to the variable x multiplied by α. The correspondi ng vectors are 90°

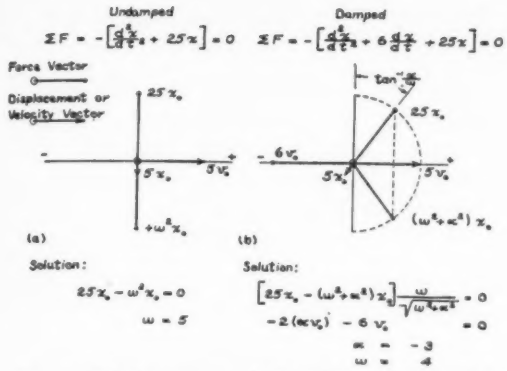


FIG. 2. Displacement—velocity—force diagram of a simple oscillator.

apart and, for the decreasing amplitude shown, the new part is directed opposite to x since α is negative.

The manner in which the two terms of the latter derivative can be combined into the projection of a single vector of length $x_0\sqrt{\omega^2 + \alpha^2}$ and ahead of x_0 by $(90° - \tan^{-1}\alpha/\omega)$, illustrates a very valuable property of the graphical representation. Any number of sines and cosines characterized by the same α and ω but bearing any phase relations among themselves may be added and the sum indicated by the projection of a resultant vector formed by geometric addition of the individual vectors. The diagram so formed at any instant retains its form for all time as all components rotate with the same angular velocity and change their length by the same multiplier. In the particular case where the sum of such a group of harmonic variables is zero, the resultant vector is also zero and the vector diagram closes on itself. This is true of the sum of the components of all forces acting at a point, and we make extensive use in the following of the fact that *the sum of vectors representing components of all forces acting at a point taken along any direction form a closed polygon, if the system is linear and the excitation harmonic.*

THE SIMPLE OSCILLATOR

The solution of the equations of motion of an oscillator having a single degree of freedom may be found by the use of the preceding ideas. Fig. 2a shows the displacement, velocity, and force vectors when no damping or excitation is present at the instant when the displacement is zero and the velocity maximum positive. The size or scale of the diagram as well as its orientation when $t = 0$ are the conditions not fixed by the equation but subject to choice. However, it is convenient in free vibration problems to draw the diagram with the velocity in the positive direction, and acceleration and displacement vectors symmetrically disposed ahead and behind, respectively. The conditions for closure of the force polygon may then be stated by two equations representing components along and perpendicular to the velocity. Having thus determined its shape, we can adjust its size and orientation to arbitrary initial conditions. In Fig. 2a there is no force depending upon velocity; so the acceleration and displacement forces must lie along the same line which will be 90° from the velocity. The condition for equality of these for an equation of motion $a(d^2x/dt^2) + cx = 0$ is

$$a(\omega v_0) \sin 90° + c(v_0/\omega) \sin (-90°) = 0$$

$$\omega^2 = c/a$$

$$\omega = \sqrt{c/a}$$

This result can, of course, be found readily enough by a straight-forward mathematical procedure.

If a damping term is present, the vector diagram is altered as shown in Fig. 2b. The conditions for closure of the force polygon now become for an equation of motion $a(d^2x/dt^2) + b(dx/dt) + cx = 0$

$$a\sqrt{\omega^2 + \alpha^2}\, v_0 \sin(90° - \psi) + c \frac{v_0}{\sqrt{\omega^2 + \alpha^2}} \sin [-(90° - \psi)] = 0$$

$$a\sqrt{\omega^2 + \alpha^2}\, v_0 \cos(90° - \psi) + bv_0 + c \frac{v_0}{\sqrt{\omega^2 + \alpha^2}} \cos [-(90° - \psi)] = 0$$

$$\text{where } \psi = \tan^{-1}\frac{\alpha}{\omega}$$

Since $\cos (90° - \psi)$ may be written as $\dfrac{\alpha}{\sqrt{\omega^2 + \alpha^2}}$, the second equation may be rewritten

$$a\alpha v_0 + bv_0 + c\frac{\alpha}{\omega^2 + \alpha^2} v_0 = 0$$

Solving

$$\omega^2 + \alpha^2 = c/a$$

$$2a\alpha + b = 0$$

$$\alpha = -b/2a$$

$$\omega = \sqrt{c/a - (b/2a)^2}$$

These equalities may be set up from the diagram more readily or may be found by direct analysis. For different amounts of damping up to critical, the locus of force vectors corresponding to $a(d^2x/dt^2)$ and cx is a circle of radius $\sqrt{c/a}$.

IDEALIZED LONGITUDINAL MOTION

In the following longitudinal stability development a system of coefficients based on Glauert[1] but revised to conform to American usage will be employed. It is essentially that used by Koppen at M.I.T. and has recently been reviewed in the Journal by Metcalf.[2] One

[1] H. Glauert, *A Non-Dimensional Form of the Stability Equations of an Aeroplane*, Br. Aero. Res. Comm., R. and M. 1093, 1927.

[2] A. G. B. Metcalf, *Airplane Longitudinal Stability—A Résumé*, Journal of the Aeronautical Sciences, Vol. 4, No. 2, December 1936.

change has, however, been made. The mean aerodynamic chord c has been used to define the moment derivatives and moment of inertia coefficient instead of the distance from c.g. to tailpost. This increases μ by the factor l/c and decreases m_u and m_w by c/l, but the products μm_u and μm_w are not changed. There appears to be some advantage in dealing with a single characteristic length for both the static and dynamic derivatives.

The equations of motion can be written

$$[-D^2 + x_u D]\frac{x}{c} + x_w D\frac{z}{c} + \mu C_L\theta = 0$$

$$z_u D\frac{x}{c} + [-D^2 + z_w D]\frac{z}{c} + \mu[D + C_L \tan\theta_0]\,\theta = 0$$

$$m_u D\frac{x}{c} + m_w D\frac{z}{c} + [-D^2 + m_q D]\theta = 0$$

where

$$D = \frac{m}{\rho/2\, SV}\frac{d}{dt}$$

$$u' = D\frac{x}{c}, \text{ etc.}$$

Linear displacements have been expressed in terms of chordlengths to facilitate drawing conclusions later about the apparent form of the oscillation as reviewed from an accompanying airplane.

A preliminary solution of these equations can be arrived at which will be quite close to the actual by omitting the terms $u'x_u$, $w'x_w$, $u'm_u$, μC_L (tan θ_0) θ, and the two inertia terms associated with z and θ. When this is done the following points can be noted.

(1) The forces induced by motion along z and θ in these directions are proportional to the velocities.

(2) The only displacement force present is $\mu C_L\theta$ through which variations in θ set up a force along x.

(3) The only inertia force present is $-D^2x/c$ through which accelerations along x produce a reaction in the same direction.

(4) All remaining forces are proportional to velocities.

If we suppose any motion at all u' to be taking place along x, a force $u'z_u$ is set up along z. If this were balanced entirely by motion along z setting up the reaction $w'z_w$ the resulting velocity along z would be

$$w' = \frac{z_u}{-z_w}\,u'$$

However, there is an additional force $\mu q'$ due to angular velocity and, as $w'm_w + q'm_q = 0$, the sum of all forces along z is

$$u'z_u + \left(z_w + \frac{\mu m_w}{-m_q}\right)w' = 0$$

$$w' = \frac{z_u}{-z_w + \dfrac{\mu m_w}{m_q}}\,u'$$

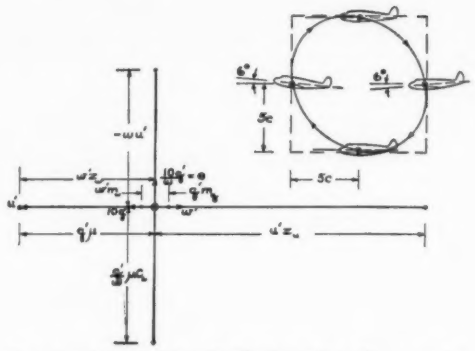


FIG. 3. Idealized longitudinal motion diagram of a typical airplane.

The apparent resistance to w' as seen by u' through $u'z_u$ is $(z_w + \mu m_w/-m_q)$ arising from q' as well as w'. Applying again the relation $w'm_w + q'm_q = 0$,

$$q' = \frac{z_u\dfrac{m_w}{-m_q}}{-z_w + \dfrac{\mu m_w}{m_q}}\,u'$$

Thus, q' is always proportional to u' for all motions along x. From this it follows from a single integration that angular displacements θ from equilibrium will be proportional to displacements along x from the average position. As $\mu C_L\theta$ represents a force along x and is actually proportional to displacements in this direction, the effect upon motion along x is the same as if a spring of stiffness

$$\text{Spring Constant} = \frac{z_u\dfrac{m_w}{-m_q}}{-z_w + \dfrac{\mu m_w}{m_q}}\,\mu C_L$$

were present there. The frequency of oscillation of the system is then

$$\omega = \sqrt{\frac{z_u\dfrac{\mu m_w}{-m_q}\,C_L}{-z_w + \dfrac{\mu m_w}{m_q}}} = -C_L\sqrt{\frac{2K}{1+K}}\ \frac{\text{radians}}{\tau}$$

where $$K = -\frac{\mu m_w}{z_w m_q}$$

Fig. 3 shows all velocities and forces in the motion and has been drawn for the following typical set of coefficients with omissions as noted above.

x_u	$= -0.15$	x_w	$= +0.5$	μC_L	$= -50$
z_u	$= -2.0$	z_w	$= -5.0$	μ	$= +50$
m_u	$= 0$	m_w	$= -0.5$	m_q	$= -5.0$
		C_L	$= -1.0$		
		tan θ_0	$= 0.1$		

In constructing this diagram it is convenient to start with an assumed unit w' drawn along the positive axis. This velocity produces the reaction $w'z_w$ along z of sign opposite to w' because z_w is a resistance and therefore negative. It also produces the torque $w'm_w$ in θ which is balanced by $q'm_q$. As m_w is negative a velocity downward along z (positive) produces a diving angular velocity (negative) such that $q' = (m_w/-m_q)w' = -0.1w'$. The velocity u' necessary to sustain the assumed w' and resulting q' is such as to cause $u'z_u$ to balance $w'z_w + \mu q'$. For unit w', $w'z_w = -5.0$ and $\mu q' = (50)(-0.1) = -5.0$. Therefore, $u'z_u = +10$ and $u' = 10/-2 = -5$. The velocity ratio existing among all three components is, then

$$u':w':q' = -5:1.0:-0.1$$

The displacement force $\mu C_L\theta = -50q'/\omega$ is shown 90° ahead of u' and the inertia force $-Du' = -\omega u'$ 90° behind it. For these to add to zero

$$-\omega u = \frac{q'}{\omega}\mu C_L$$

$$-\omega u' = (0.02)(-50)\frac{u'}{\omega} = -\frac{u'}{\omega}$$

$$\omega = 1\ \frac{\text{radian}}{\tau}$$

As the displacements x/c, z/c, θ are proportional to the velocities above, it is quite simple to show what the apparent path of this airplane will be when viewed from an accompanying airplane in uniform flight. In Fig. 3 this is shown for an assumed maximum displacement along x equal to 5 chordlengths. The displacements will be in phase and will have maximum values of

$$x/c = +5;\ z/c = -1;\ \theta = +0.1$$

When the airplane is farthest forward (positive) it is also pitched upward the most (positive) the amount being 0.1 radian or about 6°. The displacement along z is also a maximum negative equal to -1. However, the actual vertical displacement is somewhat greater than this and comes principally from the forward velocity and the angular displacement as the airplane climbs and descends along its path. This displacement is given by

$$-\int \theta\frac{V}{c}\tau d\left(\frac{t}{\tau}\right) = -\frac{\mu\theta}{\omega}$$

and is 90° ahead of θ and x/c taking account of the negative sign, and 90° behind z/c. Since maximum $-\mu\theta/\omega = -5$ as against maximum $z/c = -1$, the actual vertical displacement is $\sqrt{25+1}$ which is practically 5 and is $(90° + \tan^{-1} 1/5)$ ahead of x/z and θ. In its apparent path, therefore, the airplane reaches the top at a point ahead of the mean and has already started downward before x/c and θ become zero.

If m_q becomes zero as was assumed by Lanchester,

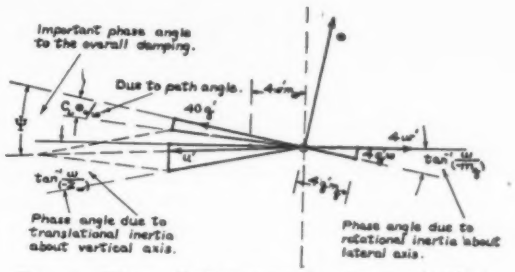

Important phase angle to the overall damping.
Due to path angle.
Phase angle due to translational inertia about vertical axis.
Phase angle due to rotational inertia about lateral axis.

FIG. 4. Phase displacements in the longitudinal motion.

$K = -\mu m_w/z_w m_q$ becomes infinite and $\omega = -\sqrt{2}C_L = +\sqrt{2}$. In this case also $\theta = (0.02)(2)x/c$ (twice as much as before) and $-\mu\theta/\omega = -\sqrt{2}x/c$ ($\sqrt{2}$ as much as before). The path then becomes an ellipse of height $\sqrt{2}$ times width and symmetrical about a vertical axis. This may be considered the fundamental apparent flight path.

PHASE DISPLACEMENTS

The effects of the two inertia terms and of the angle of the flight path which were neglected above must now be considered. Fig. 4 has been drawn to illustrate the phase relations existing among the three component velocities due to a frequency $\omega = 1$ as found for the ideal case. For the present it will be assumed that $\alpha = 0$. The impedance to motion along z now consists of a quantity proportional to acceleration as well as velocity and its vector for w' as shown will be equal to $-\omega w'$ and advanced 90° from $w'z_w$. The resultant reaction will thus be $w'\sqrt{\omega^2 + z_w^2}$ and ahead of its former position by $\tan^{-1}\omega/-z_w$. In the same way the impedance to q' becomes $q'\sqrt{\omega^2 + m_q^2}$ and $\tan^{-1}\omega/-m_q$ ahead of its former position with reference to q'.

Departures of the average flight path from level introduce a term $(\mu C_L \tan\theta_0)\theta$ by which θ reacts upon z in addition to $\mu q'$ which is always present. This changes the magnitude of the resultant reaction to $q'\mu\sqrt{1 + (C_L\tan\theta_0)^2}$ and advances its phase by $\tan^{-1}(-C_L\tan\theta_0)/\omega$ with reference to q'.

The change in magnitude of the impedances to motion in z and θ is only about 2 percent due to the introduction of the inertia terms for the typical set of quantities taken. Also, the change in the $z\theta$ coupling term for a path angle of 5° is only about 0.5 percent. It is permissible to neglect these changes entirely for the present.

The important quantity where damping is concerned is the phase angle of q' with reference to u'. It is convenient first to find that between u' and w'. The effective impedance along z as seen by u' through the term $u'z_u$ is the vector sum of two parts of approximate lengths $-z_w$, and $\mu m_w/m_q$ which for the idealized motion lie along the same line. For the actual motion this is not the case and the angle which the resultant makes with $-w'$ can be shown to be to a first order approximation

$$\frac{-\left[\frac{\omega}{-m_q} + C_L \frac{\tan \theta_0}{\omega}\right]\frac{\mu m_w}{m_q} + \omega}{-z_w + \frac{\mu m_w}{m_q}} \text{ radians}$$

q' has been shown to rotate at an angle of approximately $-(\omega/-m_q)$ radians with reference to $-w'$. Subtracting the angle of the above impedance from this,
Angle of q' with respect to u'

$$\Psi = -\left(\frac{\omega}{-m_q}\right) + \frac{\left[\frac{\omega}{-m_q} + C_L \frac{\tan \theta_0}{\omega}\right]\frac{\mu m_w}{m_q} - \omega}{-z_w + \frac{\mu m_w}{m_q}}$$

$$\Psi = \frac{-\left(\frac{\omega}{-m_q}\right)(-z_w) + C_L \frac{\tan \theta_0}{\omega}\frac{\mu m_w}{m_q} - \omega}{-z_w + \frac{\mu m_w}{m_q}}$$

Dividing through by $-z_w$ and calling $-\mu m_w/z_w m_q = K$ as before

$$\Psi = -\frac{\omega\left[\frac{1}{-m_q} + \frac{1}{-z_w}\right]}{1+K} + \frac{C_L \frac{\tan \theta_0}{\omega} K}{1+K}$$

The approximations involved in arriving at this result are quite reasonable. In calling $\tan^{-1} \omega/-m_q = \omega/-m_q$ radians, the error is only $1^1/_3$ percent for $\omega = 1$ and $m_q = -5.0$. Since $\omega/-z_w$ is an angle in the opposite direction, the total error is probably less than 1 percent.

Corrected Longitudinal Motion

The corrections necessary to bring the idealized solution of the longitudinal motion in line with the true motion include a consideration of the phase angle of q' with reference to u' as developed above along with the two terms x_u and x_w. It is not difficult to see the effect of the latter. x_u is a direct damping term along x. As w' is not out of phase with u' by more than about 5°, the force $w'x_w$ is of practically the same character. Call this an indirect damping force. The reason the phase angle can be neglected here and not elsewhere lies in the relative smallness of $w'x_w$ compared to $\omega u'$, the inertia force along x.

A change in phase of q' influences the damping in a less obvious manner. The force $\mu C_L \theta$ which θ exerts on x is delayed slightly. As shown in Fig. 5 this destroys the symmetry which the acceleration and displacement vectors along x would have about the velocity vector if no phase change were present. It is possible to approximate the effect of this by an addition to the damping force equal to the negative of the phase angle multiplied by $\omega u'$, as $\omega u'$ is nearly equal in magnitude to the displacement force $\mu C_L \theta$.

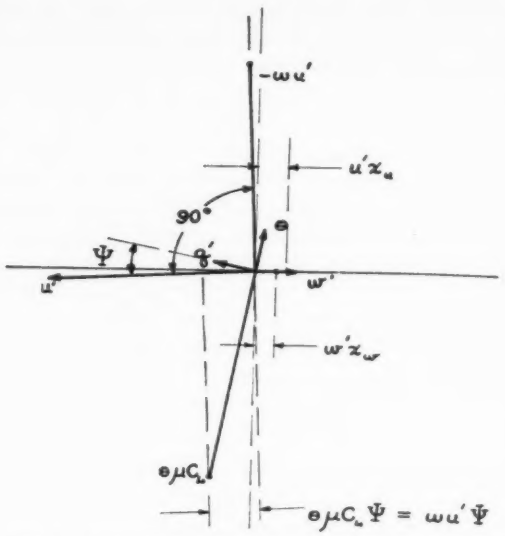


Fig. 5. Corrected diagram for the longitudinal motion.

All the effective damping forces acting in the longitudinal motion can now be grouped together. Divided by 2 they may be considered contributions to the complete damping coefficient as follows.

(1) Due to drag

$$\alpha_1 = \frac{1}{2} x_u$$

(2) Due to lift

$$\alpha_2 = \frac{1}{2} \frac{z_w x_w}{-z_w + \frac{\mu m_w}{m_q}} = \frac{C_L \frac{x_w}{-z_w}}{1+K}$$

(3) Due to phase angle of q' with respect to u' caused by mass in z and θ

$$\alpha_3 = \frac{1}{2} \omega^2 \frac{\left[\frac{1}{-m_q} + \frac{1}{-z_w}\right]}{1+K}$$

(4) Due to phase angle of q' with respect to u' caused by path angle

$$\alpha_4 = -\frac{1}{2} C_L \frac{(\tan \theta_0)K}{1+K}$$

The term m_u due to slipstream and thrust variation has been omitted up to this point. It acts upon the damping in two ways; first by modifying the frequency and thus affecting α_3 which is always positive, *i.e.*, adverse, and second through a term not depending upon frequency. By an extension of the above reasoning this term may be shown to be

(5) Due to m_u apart from the frequency effect

$$\alpha_5 = \frac{1}{2} \frac{\left(\frac{\mu m_u}{m_q z_w}\right) x_w}{1+K}$$

$$= -\frac{1}{2}\frac{\frac{m_u}{m_w}\, x_w K}{1+K}$$

The frequency of oscillation taking account of m_u becomes

$$\omega = \sqrt{\left[\frac{z_u K}{1+K} + \frac{\frac{m_u}{-m_q}}{1+K}\right]\mu C_L}\ \frac{\text{radians}}{\tau}$$

by an extension of the same reasoning, since an addition to q' due to a given u' is produced by m_u as follows.

$$\text{Change in } q' = \frac{m_u}{-m_q + \frac{\mu m_w}{z_w}}\, u' = \frac{\frac{m_u}{-m_q}}{1+K}\, u' \text{ due to } m_u$$

The period in all cases is

$$T = \frac{2\pi}{\omega}\,\tau \text{ seconds.}$$

Comparison of Results

The period and damping of an airplane characterized by the typical set of coefficients above can be found in several ways. If the determinant of the matrix of coefficients is formed in the usual way, a biquadratic in generalized frequencies results as follows:

$$\lambda^4 + 10.15\,\lambda^3 + 52.5\,\lambda^2 + 10\,\lambda + 49.625 = 0$$

for an angle of climb of $\tan^{-1} 0.1$. The usual approximate factorization gives

$$\omega = \sqrt{\frac{E}{C}} = \sqrt{\frac{49.625}{52.5}} = .97\ \frac{\text{radians}}{\tau}$$

$$\alpha = \frac{1}{2}\left[-\frac{D}{C} + \frac{BE}{C^2}\right] = \frac{1}{2}\,[-0.190 + 0.180] = -.005\,\frac{1}{\tau}$$

Gates' formula[3] in R. and M. 1118, based upon the above damping expression, but simplified, is

$$\alpha = \frac{1}{2}\left\{x_u\left[1 - \frac{{}^1\!/_2\,\mu m_w + x_u\,(z_w + m_q)}{z_w m_q - \mu m_w}\right] - 2\,\frac{x_w m_q C_L}{z_w m_q - \mu m_w} + 2\,\frac{\mu m_w (m_q + z_w) C_L{}^2}{(z_w m_q - \mu m_w)^2}\right\}$$

when adjusted to the sign system used here.
It evaluates to

$$\alpha = \frac{1}{2}\left\{-0.15\left[1 + \frac{12.5 - 1.5}{25 + 25}\right] - \frac{5}{50} + 2\,\frac{250}{(50)^2}\right\}$$

$$= \frac{1}{2}\,\{-0.15 - .033 - 0.1 + 0.2\} = -.083$$

This does not include the effect of path angle which contributes

$$\Delta\alpha = +\,C_L\,\frac{\mu m_w \tan\theta_0}{2C} = \frac{1}{2}\,\frac{5.0}{52.5} = +.048$$

Total $\alpha = -.035$.

On the basis of the formulae developed in this paper, which are in many ways equivalent to those of Gates, except for the second term in the damping expression, one obtains (since $K = -\mu m_w / z_w m_q = 1$ and $\omega = 1$)

$$\alpha = \frac{1}{2}\,[-0.15 - 0.1 + 0.2 + .05] = 0$$

It is possible to gain a good idea of the accuracy of all these answers by evaluating the biquadratic for $\lambda = j\omega = j$ and also its derivative at $\lambda = j$

$$(j = \sqrt{-1})$$

$$\phi = \lambda^4 + 10.15\lambda^3 + 52.5\lambda^2 + 10\lambda + 49.625$$
$$\phi_{\lambda=j} = (1 - 52.5 + 49.625) + j(10 - 10.15)$$
$$= -1.875 - 0.15j$$

$$\frac{d\phi}{d\lambda} = 4\lambda^3 + 30.45\lambda^2 + 105\lambda + 10$$

$$\frac{d\phi}{d\lambda_{\lambda=j}} = (-30.45 + 10) + j(105 - 4)$$

$$= -20.45 + 101j$$

Assuming that over the region of interest the function ϕ can be expressed approximately as

$$\phi = (-1.875 - 0.15j) + (-20.45 + 101j)(\lambda - j)$$

it can be said that for ϕ to equal zero

$$\lambda = j + \frac{1.875 + 0.15j}{-20.45 + 101j}$$

This is very close to the true root and has a real part

$$\alpha = \lambda e^{-\tan^{-1}\frac{\omega}{\alpha}} = \frac{(1.875)\ (-20.45) + (0.15)(101)}{(20.45)^2 + (101)^2} = -.0022$$

These four values of α may be grouped together:

Method	α
Approximate factorization $\alpha = \frac{1}{2}\left[-\frac{D}{C} + \frac{BE}{C^2}\right]$	$-.005$
Gates' formula R. and M. 1118	$-.035$
Graphically derived formula	$.000$
Solution of $\phi = \phi_{\lambda=j} + \frac{d\phi}{d\lambda_{\lambda=j}}(\lambda - j) = 0$	$-.0022$

The last method may be considered very accurate since the real part of λ comes out very close to the value assumed in forming the function. Gates' formula can be brought into line with the others by omitting the second term involving $x_u{}^2$ which change is just sufficient to cause it to correspond to the formula developed here. The simplified formula given appears to be quite good

[3] S. B. Gates, *A Survey of Longitudinal Stability Below the Stall With an Abstract for Designer's Use*, Br. Aero Res. Comm., R. and M. 1118, 1927.

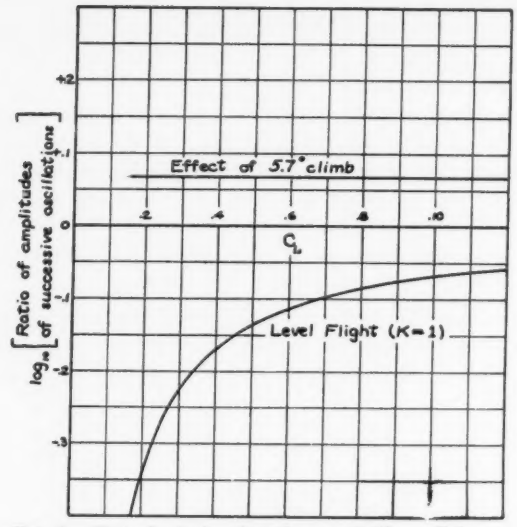


FIG. 6. Plot of relative damping at all lift coefficients and path angles.

enough for practical work and compares well with the approximate factorization. It indicates less than the true damping but greater accuracy can always be obtained by estimating the errors made in the graphical approximations.

STABILITY GRAPH

On the basis of the preceding formulae a convenient method of graphing the damping per oscillation, which is usually taken as a measure of the degree or amount of stability present, can be developed for the case where the effect of power is confined to its influence on the path angle. Under these conditions the frequency is given quite closely by

$$\omega = - C_L \sqrt{\frac{2K}{1+K}} \frac{\text{radians}}{\tau}$$

and the period by

$$T = \frac{2\pi}{\omega} \tau = 2 \frac{\pi V}{g} \sqrt{\frac{1+K}{2K}} \text{ seconds } (V \text{ in f.p.s.})$$

Dividing the parts of the overall damping coefficient separated out above by ω

$$(1) \quad \frac{\alpha_1}{\omega} = \frac{1}{2} \frac{x_u}{\omega} = \left[- \frac{C_{D_0}}{C_L} + \frac{C_L}{\pi R} \right] \sqrt{\frac{1+K}{2K}}$$

$$(2) \quad \frac{\alpha_2}{\omega} = C_L \left[\frac{1}{- z_w} - \frac{2}{\pi R} \right] \frac{1}{1+K} \sqrt{\frac{1+K}{2K}}$$

$$\text{since } x_w = - C_L \left[1 + \frac{2}{\pi R} \frac{dC_L}{d\alpha} \right]$$

$$(3) \quad \frac{\alpha_3}{\omega} = - \frac{1}{2} C_L \sqrt{\frac{2K}{1+K}} \frac{\left[\frac{1}{- m_q} + \frac{1}{- z_w} \right]}{1+K}$$

$$(4) \quad \frac{\alpha_4}{\omega} = \frac{1}{2} \tan \theta_0 \frac{K}{1+K} \sqrt{\frac{1+K}{2K}}$$

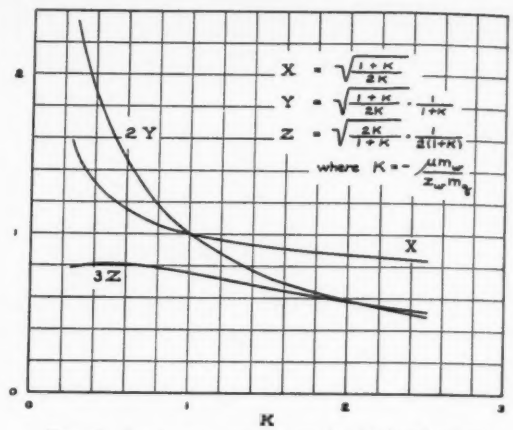


FIG. 7. Important parameters in the longitudinal motion.

In these expressions the only important variables for a given airplane are C_L, K, and θ_0. The rest are substantially fixed for all angles of attack. C_L and θ_0 take care of all possible flight variations in a given atmosphere while K covers all loadings, c.g. locations, and altitudes. The total may be written in the form

$$\sum \frac{\alpha}{\omega} = - \frac{C_{D_0}}{C_L} X + \frac{1}{4} \frac{\tan \theta_0}{X} + C_L \left[\frac{X}{\pi R} + \left(\frac{1}{- z_w} - \frac{2}{\pi R} \right) Y - \left(\frac{1}{- m_q} + \frac{1}{- z_w} \right) Z \right]$$

where

$$X = \sqrt{\frac{1+K}{2K}}$$

$$Y = \frac{1}{1+K} \sqrt{\frac{1+K}{2K}}$$

$$Z = \frac{1}{2} \sqrt{\frac{2K}{1+K}} \cdot \frac{1}{1+K}$$

This is a simple function in C_L and θ_0 but fairly involved in K. However, by plotting the three functions X, Y, Z in K as has been done in Fig. 7, the expression may be made quite flexible.

In Fig. 6, $(.4343 \times 2\pi)\Sigma\alpha/\omega$ has been plotted against C_L for the typical set of coefficients given earlier, for which $K = - \mu m_w / z_w m_q = 1$. The ordinate has been chosen in this way so as to be equal to the $\log_{10}$ of the ratio of amplitudes one oscillation apart. That part depending upon path angle has been shown separately for an angle of climb equal to $^1/_{10}$ radian or about 5.7°. It is approximately proportional to the angle and is to be added to the other part for the complete result. For other c.g. locations, loadings, altitudes, or sizes of airplane of the same form, curves for additional values of K would have to be plotted. By the use of Fig. 7 this can be accomplished quite easily. Thus, on a single sheet everything can be said about the form of the

oscillation of a family of airplanes all looking alike but of various sizes, weights, and c.g. locations. The only internal requirement is that the longitudinal radius of gyration be proportional to the size of the airplane so that m_q will not change.

Conclusions

The advantage of the approach to stability problems outlined in this paper lies in the close connection which is maintained throughout with the physical details of the actual motion. As is so often the case with alternative methods, the formulae finally written down turn out to be very much the same whatever method is followed. However, there is something to be said for a procedure where the approximations made are visually evident and subject to correction as against one where they are introduced purely for mathematical expediency. The acceptance of stability theory by engineers has been handicapped by the atmosphere of manipulation with which it is usually surrounded.

Book Review

Duralumin and Its Heat Treatment, by P. Litherland Teed; Charles Griffin & Company, Limited, London, 1937; 116 pages, ill.

This book comprises an excellent résumé of extensive tests on the heat treatment of duralumin. The static mechanical properties of this material in its commercial form are recorded in great detail and should form a useful guide to those engaged in duralumin construction. In spite of the author's disclaimer in the preface, it is written in a most lucid and agreeable style and is a work of no small literary merit.

Unfortunately, the many experiments are presented in the form of large and cumbersome tables with an unfortunate absence of conclusions derived from the many experiments. The plots, for instance, which are all too few, are plotted to linear time instead of to a logarithmic time base. Very little reference is made to relate the tests with the information previously published by others in such standard works as *"The Heat Treatment and Annealing of Aluminum and Its Alloys"* by N. F. Budgen, or the volume of the Chemical Engineering Series entitled *"Aluminum Products and Their Fabrication"* by J. D. Edwards, F. C. Frary, and Z. Jeffries.

All of the phenomena which Mr. Teed describes are already well known, although there is room for differences of opinion as to the complete explanation of the changes involved. In describing the present status of the theory of precipitation hardening, the facts seem best explained by the assumption that the early stages of hardening are due to a deformation of the space lattice of the crystal structure without invoking the actual precipitation of a microscopically visible constituent. The present-day theory may not be correct, but at least the behavior of the whole series of aluminum alloys is no more obscure than any of the other alloy systems involving hot and cold deformation and heat treatment. Mr. Teed has restricted himself to discussions of static mechanical properties although in very many cases the questions of fatigue, corrosion, and corrosion fatigue, are of the utmost importance to both metallurgists and engineers.

It is very much to be hoped that a further work is in progress which will take in this more complex field. The book is particularly valuable to those familiar with the present state of metallurgical knowledge in the field of light alloys.

A. V. deForest
Massachusetts Institute of Technology

Upper Air Study by Means of Balloons and the Radio Meteorograph

JOHN D. AKERMAN and JEAN F. PICCARD, *University of Minnesota*

Presented at the Instruments, Radio and Radio Meteorograph Session, Fifth Annual Meeting, I. Ae. S. January 27, 1937

Part I

BY JOHN D. AKERMAN

THE most common method of sending unmanned observation balloons into the stratosphere, is to send closed elastic balloons, one or two together, to carry light weight recording instruments or a radio transmitter.

To avoid duplication of effort, the University of Minnesota undertook a research problem with a very definite plan in view, as follows:

(1) Not to establish new records for altitude, but to concentrate on the development of equipment for investigation at an altitude of approximately ten miles.

(2) Since all experiments with sounding balloons so far have been based on the principle that data are gathered while the balloons and equipment are going up to maximum height, at which point the balloon bursts and the equipment starts to descend, thus giving data only during the time of ascent and descent, efforts where concentrated on the development of a ballon (Cellophane) or combination of balloons (Dewey-Almy) which would carry heavy equipment into the stratosphere and would continue to float at ceiling for a certain length of time (approximately two to ten hours).

(3) The radio meteorographs developed by other institutions have been of extremely light weight, delicate construction, low-power output and requiring special timing device to interpret signals.

The University of Minnesota undertook to develop a powerful transmitter with a range of from two to three hundred miles having a wave length suitable for radio amateur reception (five meters), and signal which, if received, would not require special apparatus in order to interpret readings.

(4) To develop a procedure whereby, with the help of receivers equipped with directional finders the location of the balloon during the flight would be known. The path of travel and the velocity of the wind could be determined from reports from different listening stations.

(5) The requirements of approximately ten-mile altitude, prolonged stay in the stratosphere, powerful transmitter, and continuous broadcasts of signal dots and dashes (for altitude, temperature, humidity, and call signals) made it necessary and possible to standardize on the equipment of an approximate gross weight of seven pounds.

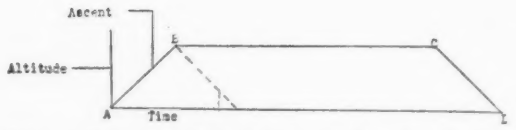


FIG. 1. Sketch showing advantages of balloon or balloons with flotation characteristics.

(6) At no time during this research were efforts made to make practical use of the data received. The use of the records after development of the equipment will involve a later step in the research program.

It is obvious from Fig. 1 that a prolonged stay of the balloon in the air gives not only the data on the atmospheric conditions during the ascent and descent of the balloon, but also might indicate if there are any changes taking place in the same mass of air during flotation of the balloon. If during the flotation period from point B to C (Fig. 1) the path of the balloon can be charted on a map with reference to time, then the velocity and the direction of the air mass movement at the ceiling altitude is available. The flotation characteristics of the ascension device to travel from B to C were first obtained by the use of Cellophane open-neck balloons as shown on Fig. 2, Plate 1 showing the Cellophane balloon. Fig. 2 shows the constructional data of the balloon, and Fig. 3, shows the train of six Dewey-Almy balloons.

During the ascent made from the University of Minnesota football stadium on June 24, the balloon traveled 613 miles in 10 hours. The inflation and launching was accomplished in a breeze of approximately eight m.p.h. and gave reason to believe that frequent launching of such balloons could be accomplished with ease at regular intervals. During the summer and fall of 1936, most of the time was spent in developing meteorological instruments, a radio transmitter, and receivers equipped with direction finding antenna so that the path of the balloon during the flight could be charted. At the same time, radio amateurs throughout the United States were contacted so that during the next ascent, they could receive data signals and record the direction of the balloon after the balloon had gone out of the receiving range of the home stations.

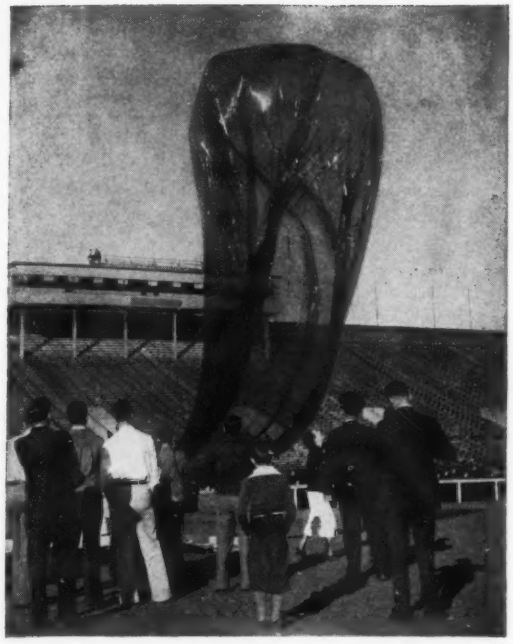


PLATE 1. Cellophane balloon during inflation.

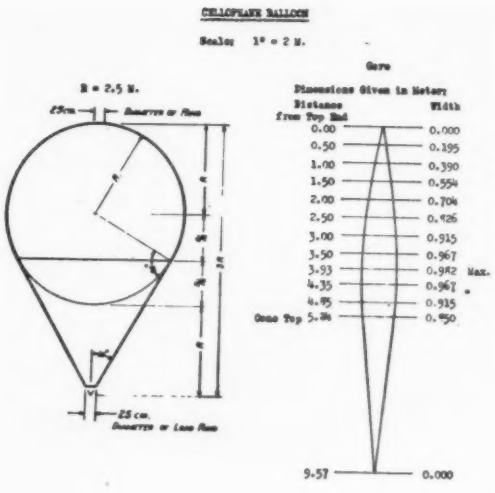

CELLOPHANE BALLOON
Scale: 1" = 2 M.
Gore
Dimensions Given in Meters
Distance from Top End
Width
0.00 0.000
0.50 0.195
1.00 0.390
1.50 0.554
2.00 0.704
2.50 0.826
3.00 0.915
3.50 0.967
3.93 0.982 Max.
4.35 0.967
4.85 0.915
Gore Top 5.36 0.850
9.57 0.000
16 Gores of #400 Cellophane 0.0012 inches thick.
Volume of inscribed sphere: 65 M3
Volume of whole balloon: 65 x 1.127 = 73 M3
Lifting Power at Sea Level (760 mm. Hg. and 53°C.): 1.5 x 73 = 110 Kg.
Lifting Power at 10 miles (769 mm. Hg. and 53°C.): 110/10 = 11 Kg.

FIG. 2. Cellophane balloon construction data.

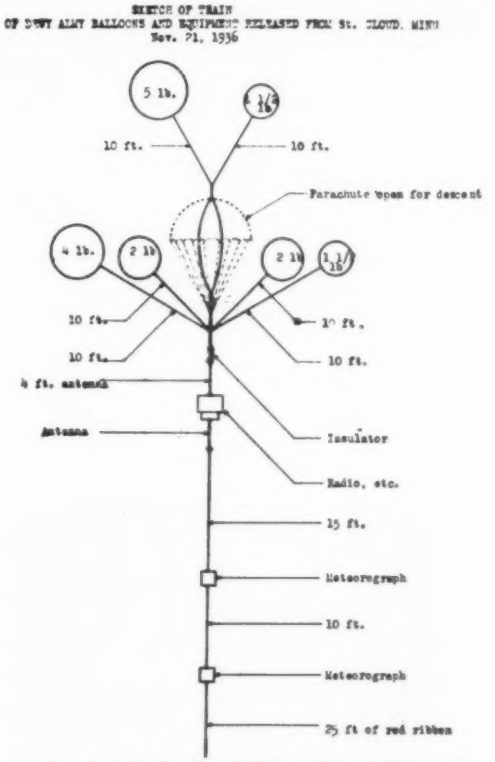


FIG. 3. Sketch of train of Dewey-Almy balloons and equipment.

The experiences with four Cellophane bags on June 24, November 14 and 18 gave definite proof that:

(1) Cellophane balloons are easy to inflate in summer time, in early morning, and in warm weather when the air is damp; and that once the balloon has taken its natural form in the air, the danger of Cellophane cracking is negligible.

(2) That at low temperatures, it is impossible to inflate the Cellophane bag so that it would take its natural form before the Cellophane would crack in the folds due to handling or wind gusts.

Abandoning the use of Cellophane in the winter months, it was undertaken to provide an ascension device which would carry heavy equipment and provide flotation at a ceiling altitude from point B to C as in Fig. 1, by means of a train of Dewey-Almy balloons. The hook-up and inflation intensities of each of the six Dewey-Almy balloons are shown on Fig. 3. On November 21, 1936, such a train was released from the St. Cloud airport. The descent of the equipment was postponed 52 minutes, in a total time of flight of two hours and twenty-five mnutes. It is obvious that with the proper number and inflation, a train of Dewey-Almy balloons can be made to provide flotation at approximately ceiling altitude for several hours.

A radio transmitter as shown on Fig. 4 and Plate 2 was constructed and enclosed in a special box shown on Plate 4 and later to be described by Jean Piccard. The 5-meter band was chosen for the reasons that a large number of amateur radio operators throughout the United States possess 5-meter receiving sets. Both home receiving sets, one located in St. Cloud and one in Minneapolis (70 miles apart), received signals clearly on loud speakers during the whole period of flight. The signals also were recived by several amateurs who hap-

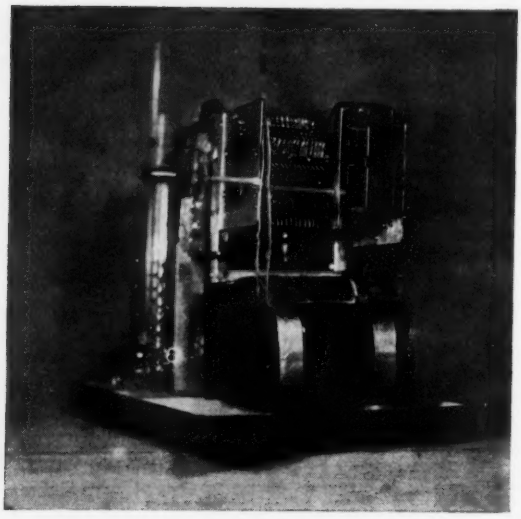


PLATE 2. Radio transmitter and automatic sending mechanism.

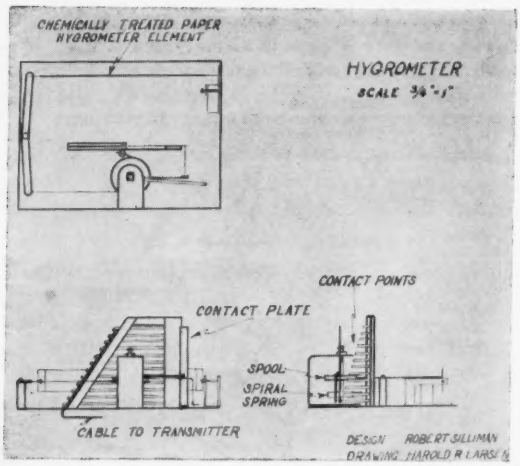


PLATE 3. Hygrometer element and electrical contacts.

PLATE 4. Insulated box for radio transmitter and instruments after the flight.

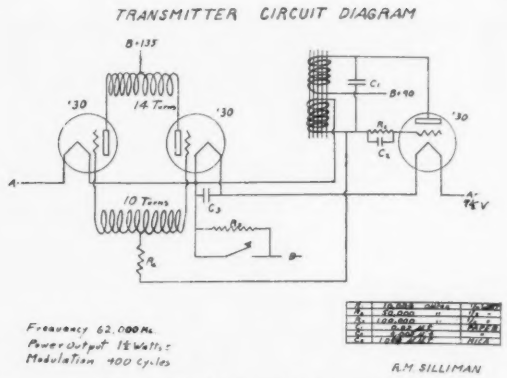


FIG. 4. Sketch of radio transmitter.

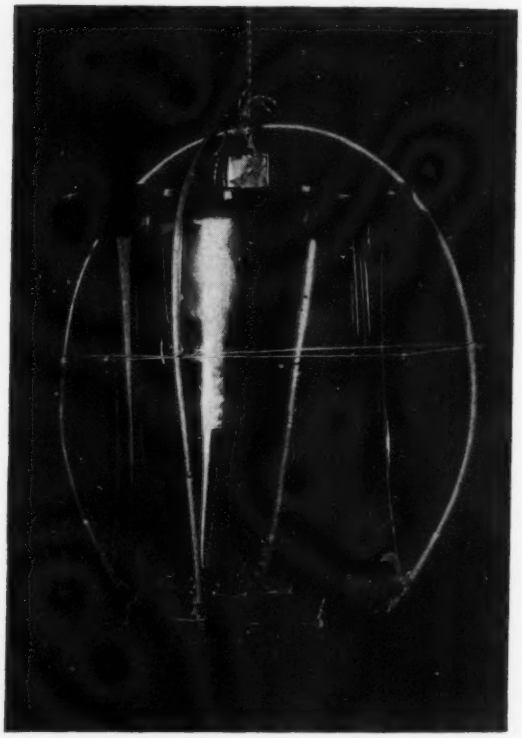


PLATE 5. Fergusson meteorograph shielded by triple ventilated wall aluminum foil shielding cage.

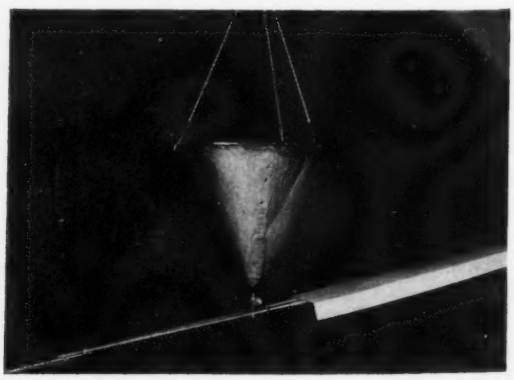


PLATE 6. Ballast control apparatus.

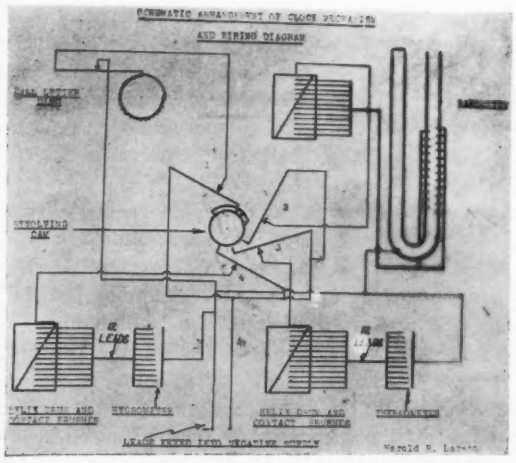


FIG. 5. Arrangement of clock mechanism and wiring diagram.

pened to be listening in, but the reports from other amateurs are missing since efforts were made to avoid too much publicity. The radio transmitter is attached to a watch mechanism driving a drum and time cam (Fig. 5) for broadcasting the following sequence and signals:

1 min. for W9XOF and a 15 sec. long dash for direction tuning.

1 min. for number of dots corresponding to height of calibrated mercury barometer.

1 min. for number of dots corresponding to temperatures as indicated by a bi-metallic thermometer.

1 min. for number of dots corresponding to humidity recorded by hygrometer.

Transmitted signals were 100 percent modulated with a 400 cycle audible tone, and frequency of the transmitted signals was 62,000 kilocycles (or 4.84 meters). In addition to the three meteorological instruments connected to the transmitter, the gondola contains a small minimum barometer, as shown on Plate 7, and a calibrated bi-metallic thermometer connected to a smoked drum for recording inside temperatures of the gondola so as to provide data for future design of batteries and watch mechanisms.

On the flight on November 21 from St. Cloud, two Fergusson meteorographs supplied by the United States Weather Bureau were attached under the gondola. Their purpose was to check the radio-recorded data. One of the Fergusson meteorographs was exposed to radiation of the sun, (see Plate 8) but had good ventilation for humidity. The other Fergusson meteorograph as shown on Plate 5 was shielded in a triple, ventilated wall of aluminum foil shielding cage which provided better accuracy for temperature readings, but might show some discrepancies on humidity. Both of these meteorographs, at present writing, have been sent to the United States Weather Bureau for deciphering of the record. After receipt of data recorded by these

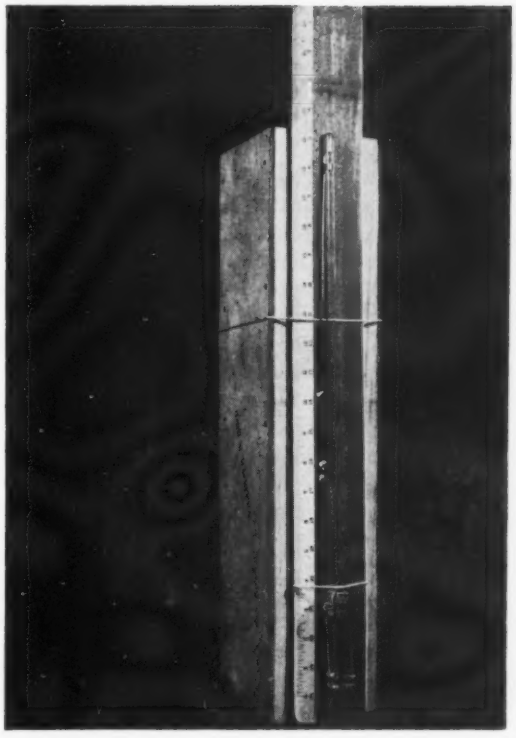


PLATE 7. Minimum barometer alongside of scale.

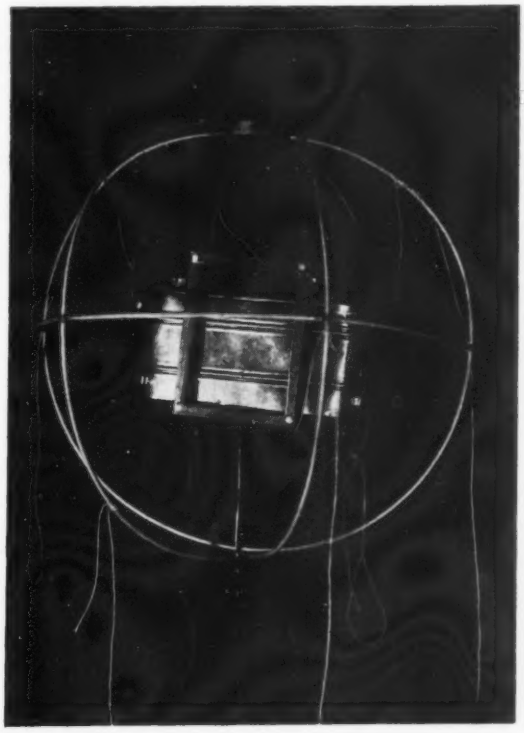


PLATE 8. Fergusson meteorograph exposed to radiation of sun.

Fergusson meteorographs, it will be possible to judge the accuracy and the defects of the radio-transmitted signals.

Part II

BY JEAN F. PICCARD

It is found convenient at the present time to gather information from the stratosphere, by means of sounding balloons, without, however, giving up the hope of making another stratosphere flight. The general plan of the research work has already been outlined by John D. Akerman, and therefore there remains for the author only to report on several specific problems.

THE FLOATING OF SOUNDING BALLOONS

Ordinary sounding balloons have a closed appendix and go up with nearly constant speed while they are expanding. When a certain diameter is reached, the balloon bursts and the instruments come down with a parachute or otherwise.

In opposite to this, the manned balloon has an open appendix. While it rises, there is a continuous escaping of gas through this appendix. The ascensional force decreases gradually and so does the vertical speed. When the free lift becomes zero, the balloon floats, and does not rise or sink.

While it is desirable for certain purposes to have a sounding balloon go up rapidly and come down immediately, there are, as Professor Akerman has explained, other cases where one desires the sounding balloon to float for several hours at about constant altitude.

For this purpose, a sounding balloon made of Cellophane has been developed which looks and behaves like the manned balloon. The development of this balloon was started in collaboration with Th. Johnson at the Bartol Research Foundation of the Franklin Institute.

It is not possible to make a rubber balloon with an open neck because the rubber would contract and expel part of the hydrogen. For this reason, the non-elastic Cellophane is used (the seams are joined with 1 in. wide "Scotch Cellulose Tape"). The balloon has a horizontal diameter of 15 ft. and a height of 22.5 ft. (Fig. 2). The upper part is a section of a sphere from its zenith down to a ring which is located at one and a half radii below the top. Here begins, tangentially, a conical part which has its apex at a point three radii below the top of the sphere. It is obvious that this conical part corresponds to the system of suspension ropes used in the old free balloon. At the lower end of the balloon there is a small wooden ring which keeps the balloon open. This ring is at the same time the "load ring" and "Poeschelring" of the free balloon.

The finished balloon weighs eight lbs. and has a volume of 73 m^3. At the start, it is inflated to about one fourth of its capacity.

The material used, called Cellophane, is a solid solution of glycerine and water in regenerated cellulose. Under proper conditions of humidity and temperature, it is of amazing toughness and the author would not hesitate, if necessary, to go up on a calm summer morning in such a balloon, slightly larger than the ones made up to the present.

During the winter time, however, when the balloon is brought from the inside of a warm building into the cold dry air, the material loses a considerable amount of moisture and its resistance against crumpling is reduced even if its tensile strength remains unimpaired. For this reason, it is advisable to use, during the winter months, not Cellophane, but rubber sounding balloons. The possibility of floating is then greatly reduced. Such investigations, like cosmic ray observations which require a long flight at constant altitude, are, therefore, better made in summer time, using Cellophane balloons.

THE AUTOMATIC BALLAST RELEASE

In the free balloon, the equilibrium is far from perfect and it usually needs the hand of a pilot to reestablish this equilibrium. The necessity of intervention by the pilot is especially great if the balloon goes up rapidly. It will then frequently be carried by its momentum beyond its position of equilibrium, causing an excessive loss of gas. Under these conditions the balloon goes down to the ground without stopping, unless the pilot throws out some of the ballast.

Placed below the gondola of the sounding balloon is a small ballast control apparatus, governed by a horizontal wind wane. (Plate 6.) As long as the balloon goes up the sand valve is closed. As soon as the balloon stops going up, sand is released until the ascent is resumed. In this manner, the authors have been able to stabilize the sounding balloon just like a manned balloon. The balloon which was released from Minneapolis in June remained in the air for ten hours and landed in Arkansas.

THE TEMPERATURE CONTROL

Many an apparatus may work perfectly well in the laboratory but will be certain to fail as soon as it has reached the stratosphere. The apparatus for sounding balloons must be constructed in such a manner that it will stand the reduced pressure and the reduced temperature. The reduced pressure acts unfavorably in two manners: it produces a relative pressure in any closed vessel and it diminishes the electric insulation given by any air layer. The intense cold freezes mercury and many other liquids, it stops the action of dry cells or storage batteries, and it stiffens the ordinary watchmaker's oil.

Utilizing the well-known fact that a black body exposed to the rays of the sun will be heated considerably above the temperature of the surrounding air, Auguste Piccard invented the stratosphere balloon, painted

the gondola black on its lower part, up to four inches above the equator, and white on the top part. In the flight from Detroit, an inside temperature of 67°F. was registered, while the surrounding stratosphere was −67°F.

The smaller the dimensions of a body, the greater will be the ratio between heat lost by convection and heat gained by insulation. The small gondolas needed for sounding balloons will not be heated sufficiently even if painted entirely black. For this reason the gondola itself is painted black and is surrounded by a transparent film held half an inch away from the painted surface. It was found that, in a gondola of this kind, the temperature will reach +60°F. when on the ground and exposed to the rays of the winter sun in Minneapolis, while the outside temperature is 0°F. In the stratosphere, the difference is, of course, much greater. The recording thermometer showed, indeed, that during one of the flights the temperature in such a gondola was +104°F., *i.e.*, about 174°F. above the temperature of the surrounding air.

The Minimum Barometer

A very light minimum barometer was constructed which was used to check and supplement other barometric readings (Plate 7). A thin glass tube, 0.1 in. in inside diameter and about 10 in. long is closed at its upper end. Its lower end dips into a small vessel filled with glycerine. While the balloon goes up, air bubbles out of the tube. When the balloon goes down, glycerine is pressed into the tube, leaving air only in its upper part. The ratio of the length of this column of air to the length of the glass tube is equal to the ratio of $p:P$ (where P is the sea level pressure and p the pressure at greatest height). A more accurate reading can be made by placing the instrument, after the flight, in a vacuum dessicator and reducing the pressure until the meniscus in the tube has reached the bottom of the tube. At this moment the pressure in the dessicator is read; it is equal to the minimum pressure reached during the flight. The whole minimum barometer with glycerine weighs only 11 grams.

The Height at Which Rubber Balloons Explode

It is usually assumed that a rubber sounding balloon will go up, expanding as it rises, until the same diameter is reached at which an identical balloon explodes when inflated with air in the laboratory. This is the ideal case and may be closely reached by balloons of exceptional quality. There are, however, grave doubts that this is always the case. In the stratosphere, the balloon is adversely affected by three different factors: the low temperature, the direct action of the ultraviolet light of the sun, and the ozone present in the air. To investigate the influence of the above factors and to find out the maximum heights possible to reach with rubber balloons, a series of experiments has been started at the author's laboratories. Balloons are being sent up with the smallest load possible. The complete gondola, protected against the cold as described above (containing the minimum barometer), and the parachute weigh only one ounce. From the minimum pressure registered, the diameter (and altitude) at which the balloon exploded may be calculated.

Books Received

Kerbspannungslehre, by H. Neuber; Julius Springer, Berlin, 1937; 160 pages, ill., RM 15.

Manuel Pratique de Construction des Planeurs et Motoplaneurs, by G. Sablier; Librarie des Sciences Aeronautiques, Paris, 1936; 160 pages, ill., 12 fr.

Flugzeug Typenbuch; Herm. Beyer Verlag, Leipzig, 1936; 336 pages, ill., RM 6.

Present Status of Stability Research

CHARLES H. ZIMMERMAN, *National Advisory Committee for Aeronautics*

Presented at the Airplane Stability and Performance Session, Fifth Annual Meeting, I. Ae. S. January 29, 1937

BEFORE going into a discussion of the present status of stability research, it seems advisable to outline the results desired. It is frequently stated that there is uncertainty as to what is desirable in the way of stability characteristics and to a certain extent that is true. It is believed, however, that certain general characteristics can be laid down as desirable. In so doing it is convenient to divide the subject into two phases, one of which may be called inherent stability, the other course stability.

With regard to inherent stability it seems desirable that there should be a moderate tendency to return to a rectilinear path, the return preferably taking the form of an aperiodic convergence. For certain types of motion the return necessarily takes the form of damped oscillations. In such cases it seems desirable that the period be long but here there is good ground for debate. The damping of rapid oscillations should be heavy, that of slow oscillations may be slight, or, put in another way, the deviations should be reduced to a very small amplitude in two or three oscillations regardless of the period. Inherent stability seems desirable at all speeds throughout the speed range with controls fixed and power either on or off. The same is true for the range of trimming speeds with controls free.

An airplane will not, of itself, return to any given course in azimuth after a disturbance. It has no sense of direction. In order to bring about stability relative to any particular course, it is necessary to provide a control operated by a device having a sense of direction, either a human pilot or a compass-controlled automatic pilot. The pilot not only operates in such a way as to make the machine stable in azimuth; he generally modifies the inherent stability characteristics with attempts to restore an even keel and the desired glide path angle. It seems not only possible but desirable that the course stability characteristics should be such that the return following a disturbance will take the form of a moderately rapid aperiodic convergence. For practical reasons course stability not only includes the nature of a return after a disturbance but also includes the nature and magnitude of the deviation resulting from a given disturbance. In general it can be said that the deviations should be as slight as can possibly be achieved, taking into account other practical considerations. Stability relative to a given course is *essential* throughout the speed range, *i.e.*, the pilot must be able to maintain any selected course in azimuth at any speed within the speed range.

There can be little doubt as to the validity of the theoretical basis for stability calculations. Fundamentally, it consists of the application of the laws of rigid dynamics to airplane motion, a treatment first given prominence in published form by Bryan in 1911. There is, however, room for doubt as to the validity of certain assumptions which have been made. Attempts have been made to obtain quantitative checks in certain instances, principally of the inherent longitudinal stability characteristics, and, in general, the checks have indicated agreements within rather wide limits. It is essential that the mathematical expressions now used be rigorously checked against free-flight behavior and altered if necessary to give the desired results. With apparatus now being developed at the N.A.C.A. Laboratory it will be possible to make those checks with free-flying models without resorting to full-scale tests.

A great deal of attention has been paid to the mathematical expressions for inherent stability and to development of suitable charts and approximate formulas for the practicing engineer. Course stability has, relatively speaking, been sadly neglected. There is urgent need for development of suitable mathematical expressions and practical methods so that the designer can estimate the course stability of the machine, including the deviations it will make in rough air, within fairly precise limits. It appears that the next marked advance in stability research will be in the perfecting of mathematical expressions, including free-flight checks, and practical methods for estimating the course stability.

Precise estimation of either inherent or course stability is impossible without accurate aerodynamic data. For convenience aerodynamic data will be taken up in relation to the normal division of motion into: (1) motion involving changes in velocity, angle of attack, and rate of pitching; and (2) motion involving changes in angle of sideslip, rolling velocity, and yawing velocity. The present status of aerodynamic data will first be reviewed in relation to the normal flight range. Consideration will then be given to stability near the stall.

In order to compute longitudinal motion it is necessary to know the variations of longitudinal and normal forces with changes in velocity and angle of attack and the variations of the pitching moment with velocity,

angle of attack, rate of rotation in pitch, and elevator setting. The force variations follow from the lift, drag, and thrust characteristics and may be determined from the data used in performance estimation. The change of moment with velocity is zero in power-off flight but cannot be neglected with power on. Many more data obtained with powered models or full-scale airplanes are needed to permit estimation of this factor with assurance of accuracy. The change in moment with angle of attack can be estimated fairly accurately by any of several analytical or graphical methods for the power-off condition. With power on much the same situation prevails as in the case of change of moment with velocity. It may be necessary to make wind-tunnel tests with powered models until airplane shapes have crystallized into a more nearly standard design. The change in moment with change in rotational velocity can neither be estimated nor measured for either the power-off or power-on conditions with satisfactory accuracy as long as the present situation prevails. It is essential to precise estimation of longitudinal stability that suitable apparatus be developed and used for systematic investigation of the pitching moment due to pitching. The variation of pitching moment with elevator setting falls in the same category as does variation of pitching moment with angle of attack.

Computation of lateral stability requires knowledge of the lateral force due to sideslip and the rolling and yawing moments due to sideslip, to rolling and yawing velocities, and to aileron and rudder settings. Systematic research is needed on lateral force due to sideslip both with and without power. Once such a research is completed this factor can probably be estimated with sufficient accuracy for subsequent designs. Rolling moment due to sideslip cannot be estimated with accuracy until adequate research has been completed showing the effect of wing-fuselage interference. Recent tests have indicated this interference to have an effect equivalent to a dihedral angle change of several degrees in certain cases. Power probably has no important effect except possibly in the case of wing engines. Yawing moment due to sideslip cannot at present be estimated with sufficient accuracy either with or without power. It is customary to measure this factor without power and to either neglect the effect of power or to make a rough calculation for it. It is essential that it be measured with power on for cases in which accurate stability estimations are desired or that a systematic research be made to show the effect of power.

Variation of rolling moment with rolling velocity must be measured if great accuracy is desired, but can be estimated or assumed to be within the limited range of existing experimental values if only fair accuracy of stability estimation is needed. A systematic research should render unnecessary measurement of this factor on subsequent designs. Variation of yawing moment with rolling velocity falls in somewhat the same class as the variation of rolling moment although there is loss yawing-moment data available. Neither of these factors is greatly affected by power with the possible exception of designs having several wing engines.

Variation of rolling moment with yawing can be estimated with fair accuracy. A systematic investigation is needed but subsequent designs should not require measurements. Power should have but slight influence. Yawing moment due to yawing cannot be estimated with accuracy either with or without power. As in the case of pitching moment due to pitching, there is urgent need for development of more apparatus and for systematic research on this factor. Since these measurements are of essentially similar natures, the same or similar apparatus can be used for determination of both pitching moment due to pitching and yawing moment due to yawing.

Rolling and yawing moments due to aileron deflection have been the subject of a great deal of research and are, in general, well known. There is need for full-scale checks of some of the low-scale data since scale effect is probably important. Yawing moments due to rudder can be estimated with fair accuracy but should be determined with a powered model when great accuracy is desired.

Stability near the stall has been the subject of a great deal of research and experimentation, the results of which can be summarized briefly as follows: Satisfactory behavior near the stall is contingent upon not allowing the flow over the wing tips to break down. This has been definitely shown to be the case by extensive experimental investigations both in England and at the N.A.C.A. Laboratory. The tips can be kept from stalling in four ways. First is the time-honored method of trusting to the pilot's skill, judgment, and vigilance. This is unsatisfactory. Second is limitation of elevator travel. This is questionable as a general method. Third is design of the wings so that the center section stalls definitely before the tips and warns the pilot. This is satisfactory for types flown by professional pilots. Fourth is design of the wings for center-section stalling, together with limitation of the longitudinal control so that the change in trim with stall of the center section will prevent stalling of the tips. This is probably desirable for airplanes to be operated by pilots who fly relatively infrequently such as, for example, owners of private machines.

Systematic research is needed on various methods of causing the center section to stall first, in conjunction with various degrees of elevator limitation and various amounts of change in pitching-moment characteristics with stall of the center section. This research should be designed to enable the practicing engineer to accomplish the compromise he desires between the perform-

ance and what might be called the "foolproofness" of the airplane and must be done full-scale. Model tests are unlikely to be satisfactory.

It appears that the present status of stability research may be summarized as follows: The basic theory is adequate but there is urgent need for extension of mathematical expressions and practical methods to cover course stability. Present and future mathematical expressions must be checked for accuracy and adequacy by free-flight tests. Aerodynamic data are woefully sparse, particularly so in regard to those reactions which arise because of rotational velocities. There is urgent need for increasing the facilities for measuring these reactions. Last, but not least, there is need for systematic, full-scale, free-flight research on those factors which most critically affect behavior near the stall. The N.A.C.A. is giving the whole problem very serious consideration with the purpose of achieving these various objectives as quickly as circumstances will permit.

Book Reviews

Air Strategy, by LIEUT.-GENERAL N. N. GOLOVINE; Gale & Polden, Ltd., London, 1936; 114 pages, ill., 7s, 6d.

The rapid advances which have been made in the performance of aircraft since the War and the high degree of specialization of types are enlarging the field of strategical and tactical employment of aircraft so that an entirely new technique is evolving. It will be apparent to readers of this book that General Golovine, formerly of the Russian Army, has had a well informed "Technical Expert" to collaborate with him, as the technical part of the book is excellent.

The book deals primarily with British Air Strategy, but contains so much material of general interest regarding military and naval aircraft that it will be found equally interesting to American readers. The author writes regarding "Doctrines":

"The United States Army Air Corps has an excellent equipment—Boeing fighters, Martin bombers, Curtiss ground attack aircraft, etc.—but the underlying strategic ideas or "Air Doctrine" are not clear, and the U. S. Army Air Corps—although complete in its own limited sphere—has little value beyond that of an Army Service with no definite object, unless the possible repetition of events in 1917–18 be admitted."

And further on he says that the doctrine accepted by the United States has suffered from the following errors:

"Lack of strategic ideas and too much attention paid to technical achievements.—Example: U. S. A."

To secure a reply to this charge it was referred to Major General Oscar Westover, Chief of the Air Corps of the U. S. Army, who wrote:

"I have not had an opportunity to read the book and so I am unable to comment upon it intelligently. However, in connection with the questions asked in your letter, the United States is today pre-eminent in aeronautical design and development. Its military organization is based on the doctrine of maintaining the minimum force necessary for national defense. The War Department has given a great amount of study to the creation of a balanced air force. The mere purchase of numbers of planes will not provide a fighting unit and they must be balanced with pilots, mechanics, and installations in order to provide an air force worthy of the name.

"Foreign nations are naturally ignorant of American war plans. The United States does not intend to conquer its weaker neighbors. The best brains in our military forces have for years been studying and perfecting plans for safeguarding our liberty. I can assure you that, in the event of an attack against the United States, the necessary plans are made to best utilize the air forces available in conjunction with the other military forces of the nation, so that operating as a team, they can prevent any invasion which may be threatened."

LESTER D. GARDNER

Alternative to Rearmament, by JONATHAN GRIFFIN; Macmillan and Co., Limited, London, 1936; 215 pages, $2.90.

Although this book deals primarily with the aerial problems of England and Great Britain, it is so fully documented with references to air power and its political consequences that it makes a valuable addition to the discussion of national defense of any country. Mr. Griffin shows the extent of dangers from air attack and reaches the conclusion that so much damage would result from bombing raids that the building of large groups of bombers for long distance operations would lay any country open to similar counter attack. The destruction he believes possible under modern conditions would be so devastating that he seeks a plan to avoid such havoc.

The first part of the book gives a summary of the possibilities both material and political of air warfare.

The second part of the book is devoted to alternative policies to the rearmament program now going on in Europe. He believes that the only way to steer between the dangers of arming for offense or of passive resistance is to combine in one policy bold collective security and strictly non-provocative national defense. He gives many well-considered reasons for defense without menace. While this conception violates all the accepted principles of air strategy he feels that air power has such potentialities for destruction that governments will have to decide whether or not they will deliberately lay their cities and population open to unannounced bombing at the beginning of hostilities. He discusses how England could secure collective security and why it is in his opinion essential.

The book is far-seeing in its viewpoint, provocative in its discussion of aerial strategy, and informative on the broad subject of air power.

Notes on the Proceedings of the Twelfth Annual Aircraft Engineering Research Conference of the National Advisory Committee for Aeronautics

Langley Field, Virginia

May 18–20, 1937

The following account of the Conference is the official statement of the National Advisory Committee for Aeronautics.

THE Twelfth Annual Aircraft Engineering Research Conference of representatives of the aircraft manufacturing and operating industries and of governmental air organizations with the National Advisory Committee for Aeronautics was held on Tuesday, May 18, 1937, at the Committee's laboratories located at Langley Field, Virginia.

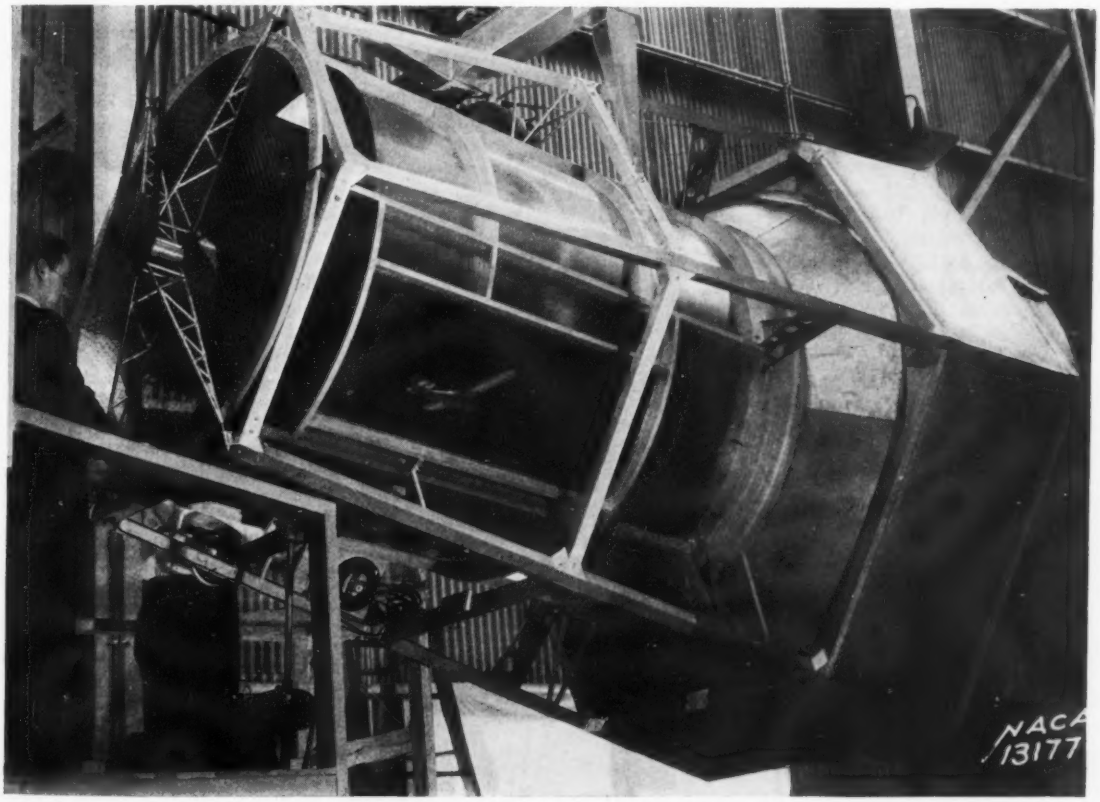
The conference is held each year to afford to the representatives of the industry an opportunity to receive first-hand reports of progress in aeronautical research at the Committee's laboratories and to witness demonstrations of the special facilities and methods used. The conference enables the Committee to obtain the comments and suggestions of the industry as to the research problems which are deemed of particular importance at the present time and which the Committee is especially equipped to study.

The conference assembled at the Post theater at Langley Field at 8:35 a.m., and at this session the most important technical developments of the Committee's research during the past year were presented by various members of the Committee's staff at Langley Field. Following this session there was an inspection of the laboratories of the Committee. At each laboratory special demonstrations were given and more detailed information presented on the activities of the particular piece of equipment during the past year.

In the afternoon the following special conferences were held at which an opportunity was afforded to obtain detailed information on the subjects in which the members of the conference were particularly interested: Airplane Performance and Design Characteristics, Aerodynamic Efficiency and Interference, Cowling and Cooling Research, Aircraft-Engine Research, Seaplanes, Rotorplanes.

The New Free-Flight Wind Tunnel

The experience of the Committee in the operation of the free-spinning wind tunnel has indicated the very great advantage of



The new N.A.C.A. free-flight wind tunnel. The first wind tunnel of its kind ever constructed where the model is unrestrained and flies freely, making possible a new method af studying airplane stability and control characteristics.

being able to reproduce and observe aircraft motion under controlled conditions in a wind tunnel. Existing methods of studying stability, control, and motion of an aircraft in existing types of wind tunnels where the model is fixed on a balance is long and laborious, and leaves much to be desired in accuracy. Realizing the need for a free-flight tunnel for studying stability, control, and motion of a model of an aircraft when flying unrestrained, the Committee has developed in the past year a new form of wind tunnel which is called a "free-flight wind tunnel."

The new type of wind tunnel is arranged so that its longitudinal axis can be set parallel to the glide path of the model under test, and the tunnel is therefore suspended from the pin so that the axis of the wind tunnel can be varied through a wide range of angles, making the wind tunnel what might be called a "tilting wind tunnel." In the wind tunnel there is a landing platform near the bottom, on which the model is placed. The air speed through the wind tunnel is gradually increased until the model takes off, flying freely in the wind tunnel and controlled by ailerons and rudder. The control surfaces are actuated by small electromagnets carried in the model, and the operator actually flies the model by means of switches operated exactly the same as the control stick or control column and rudder bar of an airplane.

Demonstrations were made in the wind tunnel indicating the value of this equipment for the study of balance, stability, riding, and control characteristics of airplanes by means of testing the model. The model when operating in this wind tunnel can be observed at close range while flying freely under the influence of the same aerodynamic and mass factors that govern its motion in flight in free air. Such quantities as elevator setting for trim, period and damping of oscillation, presence of lack of static stability about any axis, motion subsequent to a control manipulation, and many other factors can be obtained directly without resort to theoretical or empirical estimation.

Atmospheric Gust Measurements in Flight. N.A.C.A. V–G Recorder

The importance of determining the vertical upward or downward velocity of gusts encountered by the airplane is appreciated when it is realized that the maximum aerodynamic load imposed upon large air transports, bombers, and seaplanes is the load that is encountered by the wing when the airplane flies into a gust or bump of considerable intensity. The only way possible to obtain values of the gust loads encountered in flight is to actually measure them on air transports, bombers, and seaplanes operating in this country, over the Pacific Ocean, and in South America.

The Committee has developed what is known as a V-G recorder. This recorder is an instrument small enough to place in one's pocket. It is mounted in the airplane and is connected up with the air-speed measuring device. The instrument contains a device for measuring the accelerations of the airplane, and a record is obtained of accelerations *versus* air speed. The instrument has to be simple and free from operational difficulties. For instance, it is placed in the China Clipper operating between San Francisco and Manila. On the return to San Francisco the record is removed in a few seconds and shows the intensity of the air gusts or bumps that have been encountered on that trip across the Pacific and back, and the air speed at which they were encountered.

The Committee has about 160 of these instruments in airplanes and seaplanes of different types, and the results of the records determine the design factors to which an airplane wing must be built to withstand the gust intensity encountered in different parts of the world.

The maximum intensities experienced by large seaplanes or landplanes, at varying air speeds, flying thousands of hours over all sorts of terrain, were explained and showed that the average maximum up and down gust has a velocity of 30 ft. per sec.

The New N.A.C.A. Gust Tunnel

When an airplane encounters a gust of a known intensity, it is important to know the motion that is assumed by the airplane in passing through the gust, the acceleration imposed upon the airplane, which is a measure of the air load on a wing structure, and the flight path that the airplane takes in passing through the gust. This information is necessary in arriving at more rational design methods to assure safe construction of large airplanes and seaplanes. To answer these questions the Committee has developed what is known as a gust tunnel.

The purpose of this gust tunnel is to study experimentally the loads imposed on different types of airplanes models in controlled artificial gusts. The wind tunnel provides a vertical gust of a given dimension and intensity. Through this gust an airplane model is flown. To obtain sufficient velocity for the model it is catapulted into a condition of a steady glide, the model then flying through the artificial gust. The model contains a small recording accelerometer which measures the accelerations in exactly the same manner as the accelerations are measured by the V-G recorder installed in large airplanes and seaplanes. The model is also fitted with lights, which permit by the use of photographic records synchronizing the air speed, the flight path, and attitude angle of the airplane, with the accelerations obtained by passing through a known gust velocity.

The gust tunnel was demonstrated, the history of events being as follows: The model is mounted on a carriage and is accelerated down a track by a catapult. At flying speed the model takes off. The accelerometer starts to operate at this point, and the small electric lamps in the nose and tail of the fuselage light up for photographic records of the speed, path angle, and attitude angle. The action of operation of the gust tunnel is very fast, as the model is accelerated to 50 m.p.h. within a few feet. After passing through the gust the model is decelerated by a grid of rubber strands and is finally brought to a complete stop by a burlap screen. A hook on the nose of the model engages in this screen, preventing the model from dropping and becoming seriously damaged. The operation is as fast as shooting an arrow from a bow through an artificial gust.

The New N.A.C.A. Two-Control Nose-Slot Cowling for Radial Air-Cooled Engines

With the greatly increased horsepower output of the modern radial air-cooled engine, the problem of cowling and cooling the engine has assumed great importance. In the last few years the horsepower output of radial air-cooled engines has increased from 400 to 1500 hp. A limiting factor in the power that can be obtained in a radial air-cooled engine using high-compression ratio and 100 octane fuel is the ability of the cylinder and cylinder head to dissipate heat.

During the past year the Committee has made a thorough investigation of improved cowling and baffling to provide better cooling than can be obtained with the standard N.A.C.A. cowling. The ideal cowling for a radial air-cooled engine is one in which adequate cooling is provided together with high aerodynamic efficiency in cruising and in high-speed flight, and also one in which adequate cooling is obtained in the low-speed range, that is, in take-off and in climb. This is particularly true in the operation of large seaplanes. As a result of the study this year, a new two-position nose-slot cowling has been developed. With this cowling the pilot can set the nose slot for satisfactory cooling for take-off and climb. When the climb has been completed, by pushing a lever the pilot can shift to the high-speed or cruising range, where the resistance or aerodynamic efficiency of the cowling is greatly increased. This type of cowling produces the greatest pressure differential between the two sides of the cylinder at the low-speed range that has been obtained with any cowling, and it also produces the highest efficiency at the high-speed range.

The mechanical simplicity in the design of this cowling was demonstrated on a Navy fighter type airplane in the hangar.

This development marks an important step in further improving the power output and reliability of radial air-cooled engines. It places in the hands of the pilot a method of controlling the cooling of his engine and at the same time obtaining adequate cooling under any flight conditions, with the added advantage that with this type of cowling the air resistance or drag of the engine nacelle is decreased, thereby increasing the speed of the aircraft.

The standard fixed N.A.C.A. cowling has the disadvantage of providing an excess of cooling at high speed and insufficient cooling at low speed.

The new two-position N.A.C.A. nose-slot cowling has so many advantages that in the future it will undoubtedly be built in as part of the engine, just as much as the water jacket is a part of a liquid-cooled engine.

The New Radial Aircraft Engine Baffles

All radial air-cooled engines are equipped with baffles which are placed between the cylinders for the purpose of directing the airflow over the cooling fins of the barrel and cylinder head. As a result of a recent investigation conducted by the Committee, a baffle design has been developed that greatly improves the efficiency of baffles and the cooling of the engine. With a proper design of baffle and a given amount of cooling air, the efficiency of cooling can be greatly improved. With ordinary baffles only one-fifth of the available pressure is usefully employed for cooling, while four-fifths are wasted in the baffle outlet.

The Committee showed that the design of the baffle is 100 percent more efficient that the type that is ordinarily used.

Free-Spinning Wind Tunnel

Last year in the free-spinning wind tunnel it was shown that the design of the tail unit of an airplane is the most important factor in assuring a satisfactory recovery from a spin. In a spin the airflow is directed diagonally upward and toward the advancing tail, and the tail unit in order to be effective in resisting rotation of the airplane must be provided with a reasonably large vertical fin and rudder that are not shielded or blanketed by the horizontal stabilizer and elevator.

The effect of the plan form of the wing on the recovery of the airplane was not known, and results of investigations using a number of plan forms were exhibited, showing that the plan form or shape of the wing had only a moderate effect on recovery from a spin when a good tail arrangement is used.

Another unknown factor in the study of the spin problem is the effect of the airfoil section of the wing. Here again, with a satisfactory tail arrangement there is little effect, but with a poor tail arrangement a wing having a thin section gives the most rapid recovery, while flaps on the wing have an adverse effect.

There has been some question as to the recovery of an airplane where the mass, such as the engine and the passenger load, is distributed longitudinally along the fuselage, as compared with the recovery from the spin of a multi-engine airplane, where the engine mass is removed from the fuselage and distributed along the span of the wing.

In the spinning tunnel a demonstration was made of a single-engine model where the engine mass was substituted by a lead weight in the nose of the fuselage. The spinning characteristics of this airplane and the number of turns for recovery were demonstrated. The lead weight representing the engine mass was then removed from the nose of the fuselage and two weights simulating engines in the wing were placed in the wing structure.

In the investigation so far completed it has been found that the extension of the mass along the wing, as in the case of a twin-engine airplane, tends to improve recovery, while extension of the mass along the fuselage has the opposite effect. Twin-engine and four-engine transports and heavy bombers are not supposed to be spun, but it is interesting to note that in the event of circumstances placing the airplane in a spin, the mass being distributed along the span of the wing has a beneficial effect on the recovery from a spin.

Importance of Reducing Friction Drag on the Wings of Large Modern Airplanes

The continual search for means of reducing airplane drag and increasing aerodynamic efficiency was illustrated by the drag or resistance components of two different airplanes. The airplanes considered were a single-engine cabin monoplane built several years ago and a modern 4-engine transport. The tests were made in the large wind tunnel at Langley Field. The single-engine cabin airplane has a cruising speed of 136 m.p.h., and the cruising speed of the modern 4-engine transport was considered as 200 m.p.h. The significant fact pointed out is that the drag coefficient of the large modern 4-engine airplane is only 40 percent of the drag of the single-engine cabin monoplane built a few years ago. The drag of the component parts of the two different airplanes was given and it was noted that the drag of the wing of the single-engine airplane cruising at 136 m.p.h. was about one-third of the total drag of the airplane, whereas, with the modern transport airplane the drag of the wing was 50 percent of the drag of the complete airplane. This indicates the progress that has been made in eliminating or reducing the drag of such component parts as the wing struts, landing gear, engine, and fuselage.

As the drag of a wing of a modern airplane is such a large percentage of the total drag of the airplane, the importance of reducing the drag of the wing cannot be overestimated.

One of the major factors to be considered in the drag of a wing of a modern airplane is the drag of the engine nacelle, and a large model, which may be considered the large transport of the future, was shown in the full-scale wind tunnel. In this model the engines are placed within the wing, eliminating in a very large measure the drag due to engine nacelles, and indicating one important possibility of further reducing the drag of the wing.

In the modern airplane the wing is covered with sheets of aluminum alloy riveted to the main wing structure. As a large proportion of the wing drag is due to the surface friction of the wing, the Committee has investigated in 8-foot high-speed wind tunnel, at speeds from 100 to 500 m.p.h., the effect of surface irregularities, such as rivets of different sizes, countersunk rivets, the effect of lapped joints on the surface of the wing, and the effect of smoothness of the surface.

It was shown that the effects of rivets are of great importance in connection with reducing the drag of a modern airfoil of the N.A.C.A. 23012 type, either by increasing the speed of a given airplane, using a given power, or obtaining the same air speed with much less power. Consider a modern airplane weighing 20,000 lbs. and having a wing area of 1000 sq. ft., and flying at 225 m.p.h. The results of the investigation in the high-speed wind tunnel show that when using a small $^1/_{16}$-inch brazier head rivet the drag due to the rivet requires an addition of 82 hp. to fly this airplane at 225 m.p.h. Using a conventional brazier head rivet of $^3/_{32}$-inch diameter, and considering the lapped joints, at the same air speed of 225 m.p.h. the added resistance of rivets and laps necessitates the expenditure of 182 hp. over what would be required if the wing were smooth and polished.

To illustrate the importance of the smoothness of the surface, the surface of the wing was covered with a fine grain material five-tenthousandths of an inch in diameter. The effect of this slight roughness on the surface will call for an expenditure of an additional 40 hp. at 225 m.p.h. Even the addition of paint to a smooth polished surface greatly reduces the efficiency of the wing by increasing the surface friction. If a smooth and polished wing is spray-painted, 91 hp. more is required to fly an airplane having 1000 sq. ft. of surface at 225 m.p.h. In fact, in high-performance modern aircraft the importance of smooth surface in a wing is so great that it may be found economical to have

service crews wipe off the accumulated dirt and dust on wing surfaces at every stop.

At What Speed Does a "Shock Wave" Occur on a Modern Air Transport, Limiting Its Speed?

A demonstration of a modern wing fitted with an engine nacelle of conventional type in the 8-ft. 500-m.p.h. wind tunnel indicated the maximum speed at which the modern air transport can fly without excessive resistance. The modern airplane, consisting of a smooth streamline fuselage and streamline wing sections, has at the leading edge of the wing the engine nacelles which are fitted with the conventional N.A.C.A. cowling. The conventional N.A.C.A. cowling has a more or less abrupt change of section, or in other words is not as streamlined as the wing and the fuselage. With abrupt changes of section we may expect relatively high local air velocities, and when the air velocity over any part of the airplane reaches or approaches the velocity of sound, the phenomenon known as compressibility burble, or a shock wave, forms on that part of the airplane structure. The formation of this shock wave results in a very large increase in drag.

In the demonstration the air speed over the model was gradually increased up to about 325 m.p.h., and at the same time the local air speed over the N.A.C.A. cowling was also indicated. When the sum of the maximum local air speed over the leading edge of the cowling added to the air speed passing the model reached the speed of 710 m.p.h., a shock wave formed, showing a great increase in drag. The importance of this investigation showed the necessity of redesigning the N.A.C.A. cowling if modern type airplanes are to fly in excess of 325 m.p.h. A new form of cowling has recently been developed which will permit of the increase in air speeds of airplanes using the N.A.C.A. cowling up to speeds where the compressibility effect occurs simultaneously on the wing and cowling.

Elimination of Shimmy in the Forward Wheel of a 3-Wheel or Tricycle Type Landing Gear

A number of modern airplanes, both large and small, are being equipped with a 3-wheel or tricycle type landing gear. This gear has many important advantages, principally that of maintaining the stability of the airplane in landing and take-off maneuvers on the ground. It further eliminates the troublesome ground loop to which the conventional type of landing gear is subject. Probably the most important consideration in the design of the tricycle type landing gear is the elimination of shimmy in the forward castering wheel.

This subject has been under investigation by the Committee during the past year, both in model tests in the laboratory and in airplane tests on the landing field. A new method of overcoming wheel shimmy has been developed by the National Advisory Committee for Aeronautics, which is based on the interaction of tire deflection and spindle rotation. The method provides for a certain amount of lateral freedom of the castering wheel on its axis.

There was demonstrated in the laboratory a castering wheel supported on a moving belt. This wheel when first operated was subject to shimmy. By providing the proper amount of lateral freedom for the wheel on its axis, the shimmy was eliminated even under adverse conditions, such as when the wheel passes over large objects. Full-scale tests of this arrangement have been made on the W-1 airplane.

Take-Off Distance of Airplanes

Airplanes are increasing in size and in wing loading, and one of the important problems confronting both airplane designers and airplane operators is that of providing a reasonably short take-off distance for modern and future airplanes. The take-off distance required for some of our current airplanes in fact taxes many of our commercial airports. With definite trends toward larger air transports, with higher wing loadings, and corresponding increase in take-off distance, the problem has reached a critical stage. The relation between wing loading and take-off distance was shown at the conference.

In considering this problem, the take-off distance was measured from the start to when the transport cleared a 50-ft. obstacle. In general, present wing loadings do not exceed 20 lbs. per sq. ft. of wing area, and for different power loadings it was shown that the average take-off distance is from 900 to 1600 ft.

Looking into the near future, we may expect wing loadings of 35 lbs. per sq. ft. With this wing loading the corresponding take-off distances will reach from 1800 to 3500 ft., or roughly, twice that for current airplanes.

The present aids to take-off were illustrated in considering an airplane built a few years ago. For an airplane of the future with a wing loading of 35 lbs. per sq. ft. and a power loading of 10 lbs. per hp., at a speed of 250 m.p.h., without flaps and without a controllable pitch propeller, a distance of 4000 ft. would be necessary for take-off. Using a constant speed propeller this distance is reduced to 2100 ft., and using a constant speed propeller together with a good flap or high-lift device, the distance is further reduced to 1800 ft. This distance is still considered to be excessive and points to the serious consideration of using a catapult in our large airports to assist in the take-off of large air transports.

The catapult considered by the Committee would produce a maximum acceleration of one-half "g" or one-half the acceleration due to gravity.

This acceleration is not considered excessive for passenger comfort. With the use of the catapult, the constant speed propeller and the high-lift device, the take-off distance of the transport of the near future would then be reduced to 1150 ft.

Considering an airplane of the size of the new DC-4, with a high wing loading of 30 lbs. per sq. ft., and a weight of 60,000 lbs., it was shown that to take off for a distance of 1150 ft., the catapult must provide a thrust of 15,000 lbs.

If this amount of thrust is to be obtained directly from an electric motor it would require a motor of about 3250 hp. The cost of a motor of this size is such as to place it beyond serious consideration.

The catapult apparatus would necessarily be located in the center of the airport in a pit below the surface of the airport. The catapult would be on the turntable so as to permit operation in any direction to take advantage of the wind in assisting take-off. A power unit of 3250 hp. under such conditions would be difficult and expensive to operate. However, if energy is stored in a flywheel and about five minutes is allowed to bring the flywheel up to speed, it is possible to get the necessary 15,000 lbs. thrust with a flywheel of reasonable proportions by using an electric motor of relatively low horsepower and cost.

The Stall Control Flap. The Stall Characteristics of Highly-Tapered Wings for a Low-Wing Monoplane

During the year the Committee has made a study of the stall characteristics of tapered wings, such as are used on modern low-wing monoplanes. The danger of a sudden stall is well known, particularly in the event that the flow failure over the upper surface of the wing occurs violently and without warning in the region near the wing tip. The stall near the wing tip causes sudden loss of lateral control and results in an uncontrolled rolling dive, which is very dangerous. The use of efficient highly-loaded monoplanes having highly tapered wings combined with high-lift devices, tends to cause the stall to be more violent.

In considering this problem the Committee last year made one recommendation—to use a more moderate taper to the wing with twist and change of section toward the wing tip. This recommendation has been followed on a number of modern airplanes and has proved quite satisfactory. The Committee has pursued

the problem further with a view to the elimination of the sudden stall of the wing section itself. The study has resulted in a new development referred to as the "stall control flap."

The effect of the application of the stall control flap to a wing was demonstrated in the variable density wind tunnel. This demonstration was made possible by the further development by the Committee during the past year of a recording lift balance, making it possible to study accurately the lift and drag characteristics of the wing at its maximum lift or when it has reached the critical condition where stall occurs.

The character of the stall of the modern highly efficient airfoil was demonstrated, showing the stall of the wing alone and the wing fitted with a split flap. The break in the lift curve was sudden and showed the dangers of the stall characteristics of this type of wing.

The stall control flap on the model in the variable density wind tunnel was then lowered and the test repeated. Now the lift curve as it approaches its maximum lift does not reach an unstable region where the lift suddenly breaks and the lift curve drops, but the lift curve is carried over smoothly and is almost flat for a considerable period, and the angle of maximum lift reduced.

The desirable characteristics of a wing for modern high-speed high-performance low-wing monoplanes are that it have a low drag for high speed, a high aspect ratio, high taper ratio for structural efficiency and freedom from flutter, a high maximum lift coefficient coupled with gradual stalling characteristics, with a flat-top lift curve even with the high-lift devices, a non-tip stall and lateral control up to and beyond the stall, with little or no adverse yaw.

The new N.A.C.A. wing fitted with the stall control flap indicates positive possibilities in this direction. The wind tunnel investigations have been supplemented by the construction of an actual wing and flight tests on an airplane. The results of this investigation were explained both in the variable-density wind tunnel and in the hangar where the airplane equipped with this wing was shown.

Take-Off Characteristics of Large Seaplanes

With the spanning of the Pacific and the proposed flight service across the Atlantic, the development of large seaplanes has assumed an important place in our air-transport system. Some of the large seaplanes now being constructed are equipped with four engines having a total of approximately 6000 hp. This power is required by the take-off characteristics of the seaplane, and the seaplane in a cruising condition will use approximately one-half this power, or 3000 hp.

One of the most important problems studied by the Committee during the past year has been that of improving the take-off characteristics of large seaplanes, investigated in the N.A.C.A. Tank. For best take-off performance the hull must be designed to have the minimum resistance and must be taken off in a proper manner.

The designer when confronted with the problem of the design of a large seaplane, must be careful in the selection of the proper beam or width of the hull, the selection of the best angle for the afterbody keel, and the character of the surface of the hull that is in contact with the water in the take-off.

There were shown at the conference charts indicating that if the beam is too large the hump resistance of the hull may be decreased, but in the high-speed range, when the seaplane is planing, the resistance would be so great that the seaplane would not take off the water. The chart showed that for the hull investigated, by selection of the proper width of hull or beam the take-off time was 58 seconds; that by the selection in the design of the proper angle of afterbody keel this take-off time could be decreased to 48 seconds; that by the removal of the rivet heads from the bottom of the hull the frictional resistance could be decreased 9 to 15 percent, further decreasing the take-off time to 34 seconds.

The Committee has analyzed the take-off regime for the purpose of selecting the proper trim angle, which is the angle that the boat hull assumes with the horizon, so as to obtain the minimum resistance at the hump and at the planing speed. Tank tests show the proper trim angle, and if used in the take-off under discussion, the take-off time was further decreased to 27 seconds.

N.A.C.A. Trim-Angle Indicator

In obtaining the shortest take-off with minimum power in a large seaplane, the effect of the proper trim angle in taking the seaplane off the water was demonstrated in actual tests in the N.A.C.A. tank. To make practical the use of the proper trim angle, the Committee has developed what is known as the N.A.C.A. trim-angle indicator. This is another instrument that is added to the already over-crowded instrument board of the modern seaplane. It is, however, essential to determine accurately the proper trim angle for quick take-off with a seaplane.

This instrument was demonstrated in a mock-up of a seaplane. In principle it is very much like a periscope. The pilot has before him a small glass in which is reflected the horizon. This glass is graduated in degrees, so that if the optimum trim angle for take-off in the planing condition happens to be 4°, the pilot can accurately trim the hull so that the horizon line is on the 4° graduation line of the instrument.

To illustrate the importance of the trim angle, information was given as to the effect on take-off time and distance for deviations of from 1° to 3° from the proper trim angle for a modern seaplane.

Reduction of Aileron Control Force by Differential Linkage

From analysis of the results of an extensive investigation of lateral control, it has been found that probably the most satisfactory lateral-control device at the present time is the ordinary trailing-edge aileron with the gap sealed between the wing and the aileron.

On large airplanes at high speeds, the aileron control force required to pilot the airplane is excessive. In many cases a slotted type aileron having aerodynamic balance is used, which relieves the excessive force. However, ailerons of this type have been found to be less effective than ordinary sealed ailerons.

In the 7 × 10 ft. wind tunnel there was demonstrated the reduction of stick force required for ordinary ailerons by the use of a differential linkage. A large wing fitted with ailerons was mounted in the wind tunnel. The control of the ailerons was through the ordinary control stick which was actuated by a lever attached to a scale indicating the force required to move the stick for a given displacement of the ailerons. The displacement of each aileron was also indicated on the aileron linkage. It was shown, that for ailerons having an equal up-and-down displacement of, say, 30°, the control force was large.

With the use of the differential control a decrease in the amount of stick force required was indicated. It was seen that the excessive control force required was due almost entirely to the up aileron. To assist the aileron to float at a higher angle a simple method was used—that of providing the aileron with a very narrow tab deflected downward. With the use of the differential control and the use of narrow tabs, the control force required on the stick was reduced to less than one-sixth of the force required for the original aileron, or, in this particular case, to 1 lb.

Institute Notes

Wright Brothers Lecture

An innovation has been proposed in connection with this lecture which will be given by Professor B. Melvill Jones of Cambridge University on December 17, in New York. The lecture, "*Boundary Layer Experiments in Flight*," promises to be of such outstanding interest that an invitation has been received from the Pacific Coast Section to have the lecture repeated in Los Angeles on December 21.

A banquet in honor of Professor Jones would also be held. If this dual lecture can be arranged it may establish a precedent for this annual event whereby the members of the Institute living on the Pacific Coast, who cannot come to New York to hear the lecture, will be privileged to hear these lectures and the discussion almost simultaneously with the Eastern members.

Daniel Guggenheim Medal

The Board of Directors of the Daniel Guggenheim Medal Fund have decided to have the presentation of the Medal to Dr. Hugo Eckener, the recipient of the award for 1937, made at the banquet on December 17, which will be given the designation of "Honors Banquet."

Martin Commemoration Flight

On May 10, Major Gardner, Secretary of the Institute, was a guest passenger on the flight of the China Clipper from Newport Beach to Catalina Island, which commemorated the record flight of Glenn L. Martin twenty-five years ago. Dr. Clark B. Millikan, President of the Institute, presided at a dinner given in Mr. Martin's honor at Newport Beach in the evening after the flight.

Lindbergh Flight Commemoration Dinner

The Institute cooperated with the Aeronautical Chamber of Commerce of America and the National Aeronautic Association in giving a dinner commemorating the tenth anniversary of the flight of Colonel Lindbergh from New York to Paris. A distinguished committee representing many sides of New York's industrial, professional, and scientific activities arranged the dinner which was held at the Waldorf-Astoria Hotel in New York on May 20. Colonel George W. Burleigh, who was trustee of the original $25,000 prize offered by Raymond Orteig, presided. Thomas W. Lamont read a letter from Colonel Lindbergh as part of an address on the results that came from the flight. Rear Admiral Arthur B. Cook, Chief of the Bureau of Aeronautics, U. S. Navy, Charles L. Lawrance, and Colonel Norbert Champsaur also spoke.

Leighton W. Rogers, President of the Aeronautical Chamber of Commerce of America, presented the motion pictures of the Lindbergh flight and his reception in New York, which were prepared eight years ago by the Motion Picture Producers & Distributors of America and presented to the Aviation Industry for its archives by Hon. Will R. Hays.

Dinner in Honor of W. F. Durand

The Secretary of the Institute, Major Gardner, attended the dinner in honor of Dr. W. F. Durand, Honorary Fellow of the Institute, given in San Francisco on his sixty-eighth birthday on May 7.

New Benefactor Member

Another Benefactor Member of the Institute was added to the list last month when R. H. Fleet presented the Institute with one thousand dollars.

Professor A. Caquot, Honorary Fellow of I. Ae. S.

At a meeting held in Paris at the Aero Club de France on May 21 to celebrate the tenth anniversary of Colonel Charles A. Lindbergh's flight from New York to Paris, Professor A. Caquot was presented with his certificate of Honorary Fellowship in the Institute of the Aeronautical Sciences. The presentation was made by John J. Ide, representative in Europe of the National Advisory Committee for Aeronautics. Ambassador William C. Bullitt, Senator A. de la Grange, President of the Aero Club, M. Laurent Eynac, former Air Minister, M. Couhé, Director of Civil Aviation, and outstanding French aviation officials attended the meeting. Mr. Ide, in presenting the certificate, said:

"During the World's War Captain Caquot, then chief of the Balloon Section of the French Army, developed his famous kite balloons of which hundreds of the types P and R performed splendid service at the front. England adopted the Caquot balloon as standard equipment both for the Army and Navy and, in 1917, the United States likewise followed suit, this type being recognized as fundamentally superior to the American models then in existance.

"After the war, Mr. Caquot returned to civil life to resume the direction of the Pennard, Considère and Caquot Company. However, he fortunately continued his active interest in aeronautics. One of his achievements was the construction of the 3 m. tunnel of reinforced concrete at the Service Technique at Issy-les-Moulineaux, one of the largest tunnels in the world at the time of its erection.

"When the Air Ministry was created in 1928, Mr. Caquot returned to the service of the Government working with Mr. Laurent Eynac, the first Air Minister, and accomplished wonderful work as head of the scientific and technical activities of the Ministry. It was through his encouragement that so many extremely interesting prototype aircraft were developed from which were selected those to be placed in quantity production for the equipment of the Air Force.

"It was a particularly graceful thought on the part of the authorities of the Aero Club de France to have this American tribute to a great French citizen take place on the occasion of the commemoration of the crossing of the Atlantic by Colonel Lindbergh."

John J. Ide presenting the Certificate of Honorary Fellow to Professor A. Caquot at the Aero Club de France. The others in the picture are Senator de la Grange, Mme. Bleriot and Mme. Caquot.

Visitors to the Institute

Among the visitors to the Skyport recently have been W. M. Evans and H. C. Mansell of the Bristol Aeroplane Co., Ltd., Bristol, England; E. R. Desoutter of London, England; His Worship the Mayor of Blackpool, England, W. S. Ashton; A. Hessell Tiltman, Managing Director of Air Speed Limited, Portsmouth, England; Michel Wibault of Paris, France, and M. Brun of Air France, Paris, France.

Denver Meeting

The Institute will hold a meeting as part of the program of the American Association for the Advancement of Science at Denver on June 22. The tentative program is as follows:

Chairman:

Dr. Clark B. Millikan, California Institute of Technology.

(1) "The Use of a Composite Aerostat *vs.* the Charles Balloon for High Altitude Observation," Prof. Jean Piccard, University of Minnesota.
(2) "Contributions of Science to Air Transportation," Col. Edgar S. Gorrell, President, Air Transport Association of America.
(3) "Application of the Polar Front Theory to Practical Meteorological Forecasting," Hon. W. R. Gregg, Chief, U. S. Weather Bureau.
(4) "The Elimination of Snow and Rain Static in Flying Operations," H. M. Hucke, Chief of Communications Laboratory, United Air Lines.
(5) "Denver's Place in Aviation," Charles F. Horner, President, National Aeronautic Association.
(6) "The Scope of Aeronautical Bibliography," Major Lester D. Gardner, Secretary, Institute of the Aeronautical Sciences.

In the evening a dinner will be given by F. W. Bonfils, President of the National Aeronautic Association Chapter in Denver, to the guest speakers. Headquarters of the I. Ae. S. will be at the Hotel Cosmopolitan.

N.A.C.A. Annual Conference

Over one hundred members of the Institute attended the sessions of the Twelfth Annual Aircraft Engineering Research Conference of the National Advisory Committee for Aeronautics held at Langley Field on May 18 and 20. A full account of the Conference will be found elsewhere in this issue of the Journal.

Student Branches

University of Detroit. At a joint meeting of this Student Branch of the Institute and the University of Detroit Aeronautical Society, the films of foreign laboratories were presented before an audience of about 100 members and guests. Before the showing of the films, Grace Brown, an authority on international law, gave an interesting talk on her extensive travels on American, European, and Asiatic airlines. She has flown over 100,000 miles on foreign airlines, her trips including passage on the Hindenburg and the China Clipper, as well as extensive flying in China and Japan. In addition to the discussion on her airline travels she also presented some very interesting points on the operation of airlines between foreign countries.

University of Michigan. A meeting of this Student Branch was held on Thursday, April 22, at which plans for a First Annual Banquet of this Branch were discussed. Election of officers for the year 1937-38 was held, the following being elected: President, Jere Farrah; Secretary, John Reeder; Engineering Council Representative, Jack Kasley. B. L. Springer was unanimously re-elected as Honorary Chairman of the Branch for the coming year. The speaker of the evening was R. L. Thoren, Instructor in the Department of Aeronautical Engineering. Mr. Thoren presented a paper on "Soaring Flight" which was of considerable interest to those present. New possibilities in soaring, based on a more comprehensive knowledge of the different kinds of thermal currents and the aerodynamic refinements of high-performance sailplanes, were discussed in detail.

The First Annual Banquet of the Branch was held on April 29, 1937, about one hundred members and guests attending. Following the dinner, officers for the coming year were introduced. Professor M. J. Thompson was presented with a Gladstone traveling bag in recognition of the splendid work he did as Acting Head of the Department of Aeronautical Engineering in helping the students.

Professor Thompson, Toastmaster, introduced some of the older men in aviation and engineering who were present. Among these were: Colonel Clarence Chamberlin, transatlantic flyer; Professor W. F. Gerhardt of Wayne University; D. C. Maier of the Barkley-Grow Aircraft Corporation; Professor H. C. Anderson, Head of the Department of Mechanical Engineering at the University of Michigan; R. W. Ayer of the Stinson Aircraft Corporation; Lieutenant H. M. McCoy of Wright Field; and Professor F. W. Pawlowski, Guggenheim Professor in the Department of Aeronautical Engineering at the University of Michigan. Dean A. H. Lovell of the College of Engineering gave a brief talk welcoming our guests and pleading for a closer relationship between the industry and the University. R. H. Upson spoke regarding the young engineer's place in the industry today.

T. P. Wright, Vice-President in Charge of Engineering of the Curtiss-Wright Corporation, and Vice-President of the Institute of the Aeronautical Sciences, gave a talk on "Aeronautics—A Brief Survey."

University of Minnesota. Two meetings of this Student Branch were held during the month of April, one on Friday, April 23, and another on Wednesday, April 28. At the first meeting, the pictures of the aeronautical laboratories of England, Germany, and Italy were shown in the Physics Auditorium on the University of Minnesota Campus.

At the meeting on the 28th, motion pictures taken by one of the group of senior students, who recently made an inspection trip to the various Eastern aircraft companies, were shown. The pictures, though short, showed most of the points of interest visited by the touring students. Another reel of motion pictures of the ascent of one of Dr. Piccard's cellophane balloons was also presented at this meeting.

Rensselaer Polytechnic Institute. Two meetings of this Student Branch of the Institute were held during the month of May. The first, held on May 12, was a short business meeting, after which motion pictures were shown involving the latest developments and progress in the science of aerial navigation, these being supplemented by a lecture. A second short business meeting was held on May 20, at which the following officers were elected: A. L. Jarrett, Chairman; Warren Allen, Vice-Chairman; Gerald Rosen, Treasurer; and W. F. Meyer, Secretary.

Personnel Opportunities

The Personnel Bureau serves organizations seeking to employ aeronautical specialists as well as individual members. The Bureau has been the means of arranging several very successful connections for members.

Any member or organization may have requirements listed without charge.

Wanted

Opening available as Assistant Chief Engineer. Applicant must have good education, broad experience and executive ability. Familiarity with Army and Navy requirements as well as those of Bureau of Air Commerce essential. Reply should give complete details on above subjects as well as references. Write, Box 59, Institute of the Aeronautical Sciences.

Instructors for large government approved ground school, qualified to teach Aeronautical Engineering and Mechanics subjects. Give experience, training and enclose snapshot of yourself. Write, Box 60, Institute of the Aeronautical Sciences

Exchanges

The Institute exchanges the Journal with many other aeronautical periodicals. They are kept on file at the Skyport in Rockefeller Center, New York City, where members may read them. As readers of the Journal may wish to subscribe to some of them, a list of these periodicals with their addresses is published here. Information regarding subscription prices may be secured from the Secretary of the Institute.

Aero, Maneesikatu 2, Helsingfors, Finland.

Aero Digest, 515 Madison Ave., New York City.

Aeronautica Argentina, Velez Sarsfield 57, Cordoba, Argentina.

L'Aéronautique, 55 Quai des Grands-Augustins, Paris, France.

L'Aérophile, 7 Rue Sainte-Lazare, Paris, France.

The Aeroplane, 175 Piccadilly, London, W.1, England.

L'Aerotecnica, Via delle Coppelle 35, Rome, Italy.

Les Ailes, 77 Boulevard Malesherbes, Paris, France.

Aircraft Engineering, 2 Bloomsbury Place, London, E.C.1, England.

Air Law Review, Washington Square East, New York City.

Asas, Caixa Postal 1967, Rio de Janeiro, Brazil.

Astronautics, American Rocket Society, 31 West 86th Street, New York, N. Y.

Aviation, 330 West 42nd St., New York City.

L'Aviazione, Corso Umberto 504, Rome, Italy.

Boletin de Aeronautica Civil, Calle Azcuenga 923, Buenos Aires, Argentina.

Bulletin du Service Technique de l'Aéronautique, 72 Chaussee de Waterloo, Rhode-Saint-Genese, Belgium.

Bulletin of the American Meteorological Society, Blue Hill Observatory, Milton, Massachusetts.

Bulletin Officiel du R.A.A., 6, Rue du Mezieres, Paris (6), France.

Bulletin Technique du Bureau Veritas, 31 Rue Henri-Rochfort, Paris (17), France.

Canadian Aviation, Journal Building, Ottawa, Canada.

Contact, Fort Lee, N. J.

Deutsche Luftwacht, Schoeneberger Ufer 46, Berlin W35, Germany.

Der Deutsche Sportflieger, Petersteinweg 19, Leipzig C1, Germany.

Les Fiches Aéronautiques, 6 Rue Galilee, Paris, France.

Flight, Dorset House, Stamford St., London, S.E.1, England.

Flugwesen, Konviktska 22, Prague 1, Czechoslovakia.

Indian Aviation, P. O. Box 2361, Calcutta, India.

Interavia, 13, Corraterie, Geneva, Switzerland.

Journal of Air Law, Northwestern University, Chicago.

Journal of the Institute of Engineers, Australia, Science House, Gloucester and Essex Sts., Sydney, N. S. W., Australia.

Journal of Research of the National Bureau of Standards, U. S. Govt. Printing Office, Washington, D. C.

Journal of the Royal Aeronautical Society, 7 Albemarle St., Piccadilly, London, W.1, England.

Journal of Scientific Instruments, 1 Lowther Gardens, Exhibition Rd., London, S.W.7, England.

Journal of the Society of Automotive Engineers, 29 West 39th St., New York City.

Letectvi, Celetna 13, Praha I, Czechoslovakia.

Luftfahrt-Forschung, Verlag Oldenbourg, Munich 1, Germany.

Die Luftreise, Lindenstr. 35, Berlin SW68, Germany.

Luftfahrt-Literaturschau, Z.W.B. bei der D.V.L., Berlin-Adlershof, Germany.

Model Airplane News, 551 Fifth Avenue, New York City.

Model Aviation, The American Academy for Model Aeronautics, 1733 RCA Building, Rockefeller Center, New York, N. Y.

Monthly Weather Review, U. S. Dept. of Agriculture, Washington, D. C.

Motor and Flying, 24 Bond St., Sydney, N. S. W., Australia.

National Aeronautic Magazine, Dupont Circle, Washington, D. C.

Official Aviation Guide, 608 S. Dearborn St., Chicago, Illinois.

The Pilot, Grand Central Air Terminal, Glendale, California.

Il Politecnico, Via Spiga 32, Milan (2/7), Italy.

Popular Aviation, 608 S. Dearborn St., Chicago, Illinois.

Proceedings of Institute of Radio Engineers, 330 W. 42nd St., New York City.

Publications Scientifiques et Techniques du Ministère de l'Air, 55 Quai des Grands-Augustins, Paris, France.

Review of Scientific Instruments, 175 Fifth Ave., New York City.

Revue de l'Armée de l'Air, 55 Quai des Grands-Augustins, Paris, France.

Revue du Ministère de l'Air, 71 Avenue des Champs-Elysees, Paris, (8), France.

Rivista Aeronautica, Ministero dell'Aeronautica, Rome, Italy.

The Royal Air Force Quarterly, Gale & Polden Ltd., 2 Amen Corner, London, E.C.4, England.

Schweizer Aero-Revue Suisse, Gubelhangstrasse 22, Zürich-Oerlikon, Switzerland.

Soaring, 1614 Delaware Ave., Wilmington, Del.

Southern Flight, Ledger Building, Fort Worth, Texas.

Sportsman Pilot, 515 Madison Ave., New York City.

Technical News Bulletin of the National Bureau of Standards, U. S. Govt. Printing Office, Washington, D. C.

Techniczne Nowosci Lotnicze, Czerwonego Kryza 21/23 m.6, Warsaw, Poland.

Technika Vosdushnogo Flota, U1. Radio 16, Moscow 16, U. S. S. R.

La Technique Aéronautique, 2 Rue Blanche, Paris (9), France.

U. S. Air Services, Transportation Building, Washington, D. C.

Western Flying, 420 S. San Pedro St., Los Angeles, California.

Wirtschaft Technik Verkehr, Alte Jakobstr. 148/155, Berlin, SW68, Germany.

Zeitschrift für angewandte Mathematik und Mechanik, Kulmstr. 1, Dresden A24, Germany.

AERONAUTICAL REVIEWS

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps.

Aerodynamics

In Search of German and Italian Aviation—Guidonia. Captain N. MacMillan. Visit to Italy's remarkable air research establishment. Radio research; physical laboratory; hydrodynamic test house with speeds as high as 67 m.p.h.; circular tank; aerodynamic laboratory, including a supersonic wind tunnel reaching speeds of 1428 m.p.h. and some experimental results on the phenomena of ultra-high-speed air flow; and engine testing. Continued. Flight, March 25, 1937, pages 294–298, 9 illus.

Test Methods Involved in the Operation of a Commercial Wind Tunnel. B. G. Eaton, Jr. Curtiss vertical open-throat closed-return Goettingen-type wind tunnel with an 8-ft. jet diameter. Description of tunnel and its flow characteristics, models used, six-component balance, convenience of operation, and some special investigations. Aero Digest, April, 1937, pages 28–29, 46, 100, 4 illus.

Aircraft Design

The Computation of the Lift Distribution Over the Span. M. M. Munk. Determination of downwash called into play by a given lift distribution and use of the upwash for computation of downwash caused by any lift distribution. Journal Aeronautical Sciences, March, 1937, page 198.

Short method for determination of downwash from span lift distribution in absence of sweepback, by the use of diagrams. Aero Digest, April, 1937, pages 42 and 94, 3 illus.

Longitudinal Stability. W. R. Andrews. Formulas for design of tail surfaces for satisfactory longitudinal stability. Vertical c.g. position is allowed for and particular reference made to low-wing monoplanes. To improve stability, tail plane span should be increased, and the chord kept the same (or less). Further improvement can be made by decreasing the elevator chord and by increasing that of the fixed tail. Tail volume formula is checked and it is shown exactly how the c.g. of an airplane should vary with position of the wing with respect to c.g. Formulas for normal force plane (biplanes and monoplanes) and mean tangential force plane conclude this installment. To be continued. Flight, Aircraft Engr. Sup., March 25, 1937, pages 15–19, 2 illus., 1 table, 11 eq.

Pressure-Distribution Measurements in Flight on a Wing Section With Landing Flaps. G. Kiel. Pressure distribution at various landing-flap deflections measured on a wing section in flight. Results of measurements, their evaluation, experimental installations, and measuring method adapted to flight tests. DVL report. Luftfahrtforschung, February 20, 1937, pages 71–84, 27 illus., 3 tables, many equations.

Wing Flutter. A. G. Pugsley. New problems introduced by heavy wing loadings. Increasing torsional stiffness by using heavier gage covering, natural mass balancing by rearrangement of wing-engine positions, and bringing wing-structure weight forward towards the wing flexural axis in single-engined planes suggested. Brief abstract of Royal Aeronautical Society paper. Flight, April 15, 1937, page 366.

Alighting Gear

Design of Alighting Gear Shock Absorbers. W. Stieda. Design of shock absorbers according to German aircraft specifications. Equations for determining work resiliency of load cases and specified load factors, general requisites in the design of alighting gear, and numerical examples. Luftwissen, January, 1937, pages 2–6, 11 illus., 3 tables, many equations.

Wind Tunnel Measurements for Airplane Landing Skis. M. Kohler. Aerodynamic advantages of fairing airplane skis and their mountings. Bonding up of the stern part exerted considerable influence on the character of the polars and moment curves of the skids. Parallel arrangement of like skis had an effect on the polar curve similar to an increase of aspect ratio for wings and the moment curve did not undergo any considerable transformation thereby. Test results. Luftwissen, January, 1937, pages 6–12, 10 illus., 15 tables.

High-Altitude Aircraft

Air Transport Looks Aloft. R. M. Cleveland. Flight of transport planes in the stratosphere. General discussion referring to four-engined Boeing 307 transports with pressure cabins for Pan American and TWA, experimental "overweather" flying of D. W. Tomlinson for TWA, intensive studies of oxygen-deficiency effect by United Air Lines, and a study of high-altitude aircraft design made by M. E. Gluhareff, Sikorsky Aircraft Corp. Scientific Am., May, 1937, pages 294–296, 4 illus.

The Economics of High-Flying. J. Millar. Analysis of altitude performance of a modern high-speed twin-motored transport. Effect of height on speeds; correct height for making the best time over a given distance with maximum economy; relation between schedule speed, length of trip, strength of wind, and height; effects of winds on distance covered in climbs to and glides from various heights; relation between distance covered and height of climb or glide; and saving effected on trips of varying lengths by climbing to various heights. Aeroplane, Aeronautical Engg. Sup., April 7, 1937, pages 403–405, 2 illus., 2 tables.

Airplane Flight to and in the Stratosphere. R. J. Smith. Propeller part of the power available for stratospheric flight and design of a cabin for stratoplanes. Stiffening and jamming of controls on ascent to high altitudes, considered due to low-temperature effects, studies of lubricants, and development of bearings operating without lubrication also referred to. Continued. AeroDigest, April, 1937, page 40, 1 illus.

Stratosphere Airplanes. Aerodynamic problems, advantages of stratospheric flight, and characteristics of the Farman 1000 and 1001, Junkers Ju-49 and Ju-49bis, Guerchais 011, and Miller stratosphere airplanes, designed or built, and of the Boulet French military airplane designed. L'Aérophile, March, 1937, pages 59–61, 5 illus., 1 table.

Rotating-Wing Aircraft

About Rotating-Winged Aircraft. T. Mohring. The helicogyro has inherently greater high speed possibilities than the gyroplane and helicopter, according to this analysis of the three types of rotating wing aircraft. Fairchild F-45 and the Kellett Autogiro KD-1 are compared, and limits of the gyroplane, helicopter, and helicogyro discussed. Probable flow around the rotors, production of lift by the rotors, and balance and control are considered. Long abstract. Aeroplane, Aeronautical Engg. Sup., April 14, 1937, pages 435–438, 16 illus., 1 table. Original article. Luftwissen, August, 1936 and January, 1937, pages 208–214 and 12–21, 30 illus., 1 table, many equations.

The Ideas of Mr. Nagler. Novel type of helicopter is referred to in which a Pobjoy engine drives both the two-bladed rotor and a pusher propeller mounted at the back of the pilot's nacelle. Earlier Nagler designs also mentioned. Aeroplane, April 7, 1937, page 406, 4 illus.

Stress Analysis and Structures

Graphs for the Determination of Stability of Two-Dimensional Bar Groups K. Borkmann. Use of the curves is illustrated by examples and it is shown how the single bars of bar structures are combined in suitable bar groups for the determination of stability. D.V.L. report. Luftfahrtforschung, February 20, 1937, pages 86–92, 5 illus., 9 tables, many equations.

Metal for the Light Airplane. J. P. Eames. Stressed metal skin construction is compared with tubular construction. To be continued. Western Flying, April, 1937, pages 15–17, 4 illus.

On the Calculation of the Box Girders. L. Kirste. Method based on study of internal deformations or differences in level, uniting all the unknown variables into one only which can be determined graphically. L'Aéronautique, L'Aérotechnique Sup., January, 1937, pages 1–6, 10 illus., 19 illus.

Simplified Method of Beam Analogy. E. H. Watts. Column analogy method of Professor Hardy Cross is explained by means of which continuous frames, such as bulkhead rings, can be comparatively easily solved. Examples of its application to beams fixed at the ends, to analysis of frames of curved sides, varying moments of inertia, unsymmetrical loading, or other complicated analysis. Aero Digest, April, 1937, pages 48, 50, 52, 11 illus., 3 tables, 3 equations.

Stresses on Ring Bulkheads at the Introduction of Longitudinal Forces in Cylindrical and Conical Shells. K. Drescher and H. Gropler. Numerical data for magnitude of bending moments in two bulkheads arranged near the point of application of longitudinal forces. These forces act as single forces at the ends of monocoque fuselages, at the cutaway portions of the pilots cockpit, and at wing-fuselage connections, and are to be absorbed by the adjacent shell construction. The shell is assumed as cylindrical or conical and its cross section as circular or elliptical. Report, Flight Technique Institute, Technische Hochschule, Berlin. Luftfahrtforschung, February 20, 1937, pages 63–70, 12 illus., many equations.

Aircraft

Czechoslovakia

Avia 122 for Training in Acrobatics. Single-seater Czechoslovakian biplane designed especially for inverted flight and powered by an Avia RK-17 350-hp. engine. Design, characteristics, performance. L'Aérophile, March 1937, pages 50–51, 1 illus.

France

Breguet 462 High-Speed Bomber. A. Frachet. Bomber powered with two Gnôme Rhône 14-No. 950-hp. engines, attained 400 km. per hour and at over 350 km. per hour transported 1000 kg. of bombs over 1000 km. Long description and reference to armament. Les Ailes, March 18, 1937, page 8, 4 illus., 2 tables.

New Airplanes in Tests. Brief references to aircraft being tested. First issue—Latécoere 582 reconnaissance and bombardment flying boat, passing its approval tests carrying a 1800-kg. disposable load and having a range of 1800 km.; Gourdou 521 dive bomber designed for the aircraft carrier Bearn; modified Amiot 144; Potez 63 powered by two Gnôme Rhône 14-Mars engines; and the Potez 65 troop transport equipped with two Hispano-Suiza 12 Ybrs 690-hp. engines.

Second issue—Potez 63 equipped with two Gnôme-Rhône 14-Mars, Gourdou S21. Les Ailes, March 18 and 25, 1937, pages 4 and 7.

Germany

An Anglicised Newcomer. German B.F.W. Messerschmidt Taifun four-seater low-wing monoplane (240-hp. Argus As 10-C aircooled inverted-vee). Maximum speed 187 m.p.h. Ceiling 21,300 ft. Few details. Flight, April 8, 1937, page 357, 2 illus.

The Four Winds. A 600-hp. Junkers Diesel is specified as an alternative power plant to the liquid-cooled B.M.W. in the German Arado 68 single-seater fighter. Brief ref. Flight, April 15, 1937, page 369.

Stand-Still Landings in Rhodesia. Heinkel H.E. 64D, formerly belonging to the Royal Aircraft Establishment, is fitted with automatic flaps worked by the inner leading-edge slots so that as the slots open the flaps come down and vice versa. With slots open and flaps down it is said the airplane makes a perfectly controlled vertical descent without any spinning tendency. Brief note. Aeroplane, April 14, 1937, page 428, 1 illus.

GREAT BRITAIN

Bristol Brethren. "Britain First," or type 142 (famous prototype of the Blenheim medium bomber), the Blenheim medium bomber, and Bristol 143 low-wing monoplane designed for transport of passengers, freight, and mail. Few details. Flight, April 8, 1937, page 348-b, 1 illus.

Names of Aircraft and Engines. Bristol bomber-transport airplane is named Bombay I. New Rolls Royce 12-cylinder vee ethylene-glycol cooled airplane engine for installation in the Battle airplane is the Merlin I. Rolls-Royce 12-cylinder vee ethylene-glycol cooled engine to be installed in the Spitfire and Hurricane airplanes is the Merlin II which embodies a modified form of cylinder block. Brief reference. Flight, April 1, 1937, page 330.

Salute to the Ensign. New Armstrong Whitworth AW-27 42-seater transport powered by four 800-hp. 14-cylinder Armstrong Siddeley Tiger engines. Very long description of new Imperial Airways airplane with cutaway drawing showing layout and berths, drawings of structural features and photographs. Flight, April 1, 1937, pages 316–322, 13 illus. Aeroplane, March 31, 1937, pages 377–382, 17 illus.

War Paint. "Shadow shading" schemes evolved for camouflaging R.A.F. bombers and Army cooperation aircraft. Brief reference. Flight, April 15 1937, page 361.

Photographs Only. Production-type Hawker Hurricane single-seater fighter and the P-4 two-seater bomber in flight, both powered by a Rolls-Royce Merlin. Flight, April 1, 1937, pages 314 and 323, 3 illus.

Hawker P.4/34 prototype high-speed light bomber having a Rolls-Royce Merlin with a new type of combined glycol radiator, oil cooler and air intake and new streamlined exhaust collectors. "The cockpit enclosure is one of the neatest of its kind yet seen." Flight, April 1, 1937, page 330, 1 illus. Aeroplane, March 31, 1937, page 366, 1 illus.

Geodetic Vickers Wellington, the new Hawker light bomber (Rolls-Royce Merlin), Bristol Blenheim (two 850-hp. Bristol Mercurys), and the Fokker Faucheur bomber (two 700-hp. two-row Hispano-Suiza radials). Aeroplane, April 7, 1937, pages 393–398, 10 illus.

Latest type of Gloster Gladiator (850-hp. Bristol Mercury) to be issued to squadrons of the Air Defence of Great Britain. New Hawker light bomber (Rolls-Royce Merlin). Aeroplane, April 14, 1937, pages 424–425, 2 illus.

Blackburn Shark seaplane for torpedo work, spotting for guns and general reconnaissance. Flight, April 15, 1937, page 375, 1 illus.

Fokker Faucheur attack estimated to do 280 m.p.h. at 11,500 ft., and Bristol Blenheim which should do 292 m.p.h. at 14,500 ft. Flight, April 15, 1937, page 369, 4 illus.

Handley Page Harrow heavy bomber being produced in two forms for the Air Ministry. Mk. I has moderately supercharged Pegasus X's (850 hp. at 4000 ft.) and Mk. II mounts Pegasus X's fully supercharged and giving 820 hp. at 9000 ft. The Harrow may be used also as a troop transport. Flight, April 15, 1937, page 360.

Production-type Bristol Blenheim medium bomber (two Mercury VIIIs) "dazzle-painted" for entry into the Service. Flight, April 1, 1937, page 327 1 illus.

Vickers Wellington medium bomber (latest Pegasus engines) ordered in quantity for the R.A.F. Attention is called to the fact that crankcase cowlings of a type popular in the United States for some years have been fitted experimentally. Flight, April 1, 1937, page 325, 2 illus.

Foreign News in Brief. New Armstrong-Whitworth high-performance medium bomber for the R.A.F. now undergoing test flights. Few details.

Trial flights of the Mayo composite aircraft are planned within a few months. Few details. Aero Digest, April, 1937, page 91.

An Intriguing Two-Seater. Baynes Bee monoplane with two Carden-Baynes S.P. 1 flat "buried" engines and pusher propellers. Long description and drawings illustrating installation of the engines in the wings, and construction and design of the airplane. Flight, March 18, 1937, pages 289–290, 4 illus. Aeroplane, Aeronautical Engg. Supp., March 17, 1937, pages 326–328, 10 illus.

Rotating-Wing Aircraft. Four experimental British types, namely, the Nagler Helicogyre, Weir jump-start autogiro, Kay gyroplane, and Hafner A. R. III gyroplane described. Flight, March 18, 1937, page 266, 4 illus.

British Light Aircraft Reviewed. Twenty British light aircraft described and a few details of American airplanes on the British market given. Flight, March 18, 1937, pages 253–265, 32 illus.

HOLLAND

Koolhoven F.K.-52 Two Seater Combat Airplane. A. Frachet. Airplane equipped with a Bristol Mercury-VIII 880-hp. engine is designed as an interceptor and cooperation airplane, flies at 370 km. per hour at 4750 meters and cruises at 315 km. per hour. Design, characteristics, and performance, and reference to armament. Les Ailes, March 25, 1937, page 8, 6 illus., 2 tables.

ITALY

The Four Winds. Flying a Breda 88 twin-engined fighter, F. Niclot on April 1 established a new world's speed record over 100 km. His speed was 517.836 km. per hour (321 m.p.h.). A batch of Breda 88s has been ordered for the Italian Air Force. Brief ref. Flight, April 8, 1937, page 395.

Results over a 1000-km. course. Brief reference. Flight, April 15, 1937, page 380. Aeroplane, April 14, 1937, page 424.

Italy's Martlesham. Captain N. MacMillan. Visit to Montecelio airport located alongside of Guidonia, a few details of some famous Italian military aircraft, and some observations on the Caproni factor. Flight, April 8, 1937, pages 340–343, 8 illus.

Jona J6. Airplane With Oscillating Wing. Biplane in which the lower wing is fixed while the upper wing is articulated to a cabane in such a manner as to conserve its freedom of roll. Long description. Rev. de l'Armée de l'Air, February, 1937, pages 221–227, 10 illus.

Vale Pursuit Trainer. Small Italian single-seater having a Farina 130-hp. engine and speed of 250 km. per hour is now in service in the Regia Aeronautica. Photographs and reference to its performance. Rev. de l'Armée de l'Air, February, 1937, pages 227–229, 4 illus.

JAPAN

Japan Design Plane. Airplane designed at Tokyo Imperial University will have a wing span of 90 ft., and a range of 7000 miles, will weigh 10 tons, and will be powered by experimental gasoline engines. Difficulties in finding adequate airport space, and reference to design. U. S. Naval Inst. Proc., April, 1937, pages 584–585.

The Heavenly Breeze. Kamikaze Mitsubishi all-metal low-wing monoplane described was flown by Iimuma and Tsukagoshi from Tokyo to London and is of Japanese manufacture. It is smaller than the Northrop airplane it is popularly supposed to represent, and its undercarriage cleaner. It is powered by a 550-hp. Nakajima Kotobuki engine which seems to be a Japanese-built Wright Cyclone and the propeller appears to be a Japanese-built version of the Hamilton. Aeroplane, April 14, 1937, pages 427 and 439, 5 illus. Flight, April 15, 1937, pages 374 and 376, 4 illus.

Japanese Aviation. P. M. Magruder. "Japan is perhaps three years behind the rest of the world in air power, but in the growth and development of industries which are necessary for the proper future of her aviation Japan is first." Total first-line strength of the Imperial Army and Navy Air Services is 1700 to 1800 planes, of which less than 20 per cent are modern aircraft. Development of aviation in Japan, aircraft and engine manufacturers, present types of military and naval aircraft, navy observation planes, and reconnaissance flying boats. Aero Digest, May, 1937, pages 26–29, 11 illus., 1 table.

U. S. A.

The Aircraft Show at Los Angeles. J. G. Thompson. Waterman Arrowbile and Arrow Sport, automatic deicing of propellers on the Lockheed 12-A, the Beech D-17W, Taylorcraft Model A, Cessna C-37, and Swallow Model C airplanes, the Continental W-67 engine and its Marvel fuel injection system, Studebaker-Waterman converted automobile engine, Goodrich-Palmer-Haynes hydraulic airplane-wheel brake, Pesco accessory drive gear box, Scintilla ignition units, Switlik Com-Pak parachute, and Jaeger electric-chronometric tachometer and True-speed indicator. Few details. Western Flying, April, 1937, pages 8–11, 3 illus.

American Military Airplanes. Vultee attack bomber with a top speed of 385 km. per hour, and Boeing YB-17 four-engined bomber attaining a speed of 400 km. per hour. Photographs only. L'Aérophile, March, 1937, page 50, 3 illus.

American Racing Airplanes. Characteristics and performances of 10 airplanes and the Menasco engines powering them. L'Aérophile, March 1937, pages 56–58, 4 illus.

Back to Boeings. "The fact that the Boeing people have been doing high-level research for the U. S. Army coupled with the success of the four-motored Boeing 299 has caught the fancy of both P.A.A. and T.W.A." Reference to new Boeing planes for these companies and to a four-motored bomber. Abstract from Time (New York), March 1. Aeroplane, March 31, 1937, page 385.

Gyroplane on Floats. Wilford XOZ-1 float gyroplane built for the Navy. Few details. Scientific Am., May, 1937, pages 317–318, 1 illus.

Long-Range Northrop Bomber. Description of bomber and its armament. Rev. de l'Armée de l'Air, February, 1937, pages 235–238, 5 illus.

A Martin Super-Clipper. Martin 156, 46-passenger Clipper. Few details. Flight, April 8, 1937, page 348.

Nascent Giants. Douglas D.C. 4 and Boeing four-engined monoplanes for Pan American and TWA. Few details of each and of the cabin air-conditioning plant for the Pan American 307. Drawing of the 307 showing cabin layout. Flight, April 8, 1937, page 347, 1 illus.

A Versatile Training Plane. Seversky SEV-X-BT advanced trainer. Few details and military uses. Scientific Am., May, 1937, page 317, 2 illus.

Airplanes for 1937. Photographs and drawings of 98 types of American aircraft, including military, and technical details of 161 airplanes in tables of specifications. Aviation, April, 1937, pages 35–75, 196 illus., 1 table.

An American Arrival—The Lockheed Twelve. Description of the airplane, illustrated by drawings and photographs, and points from the paper presented by H. L. Hibbard over a year ago before the D.V.L. and Vereinigung fuer Luftfahrtforschung. Aeroplane, March 24, 1937, pages 347–350, 5 illus.

Beech Aircraft Produces New Plane With 250 M.P.H. Top. Beech D-17-W four-passenger biplane powered with a Wasp Jr. SC-G engine cruises at 235 m.p.h. and lands at 55. Specifications and equipment. Western Flying, April, 1937, page 30, 1 illus.

Douglas Aicraft. Specifications and performance of the giant DC-440-passenger airplanes compared with those of the DC-3. Equipment includes four 1250-hp. engines and tricycle landing gear. Brief. Western Flying, April, 1937, page 32, 1 illus., 1 table.

New High-Wing Aeronca Model K. Two-place strut-braced monoplane described is powered by a 40-hp. Aeronca E-113C engine and has a maximum speed of 93 m.p.h. Aero Digest, April, 1937, pages 56–58, 5 illus., 1 table.

New Race Plane Built. Powered by a 90-hp. English Pobjoy engine, the small plane built by a group of Consolidated Aircraft Corporation employees is said to have a top speed of 200 m.p.h. Few details. Western Flying, April, 1937, page 42.

Stinson Reliant Wing Structure. Metal wing structure used on Stinson Reliant airplanes. Construction details. Brief. Aero Digest, April, 1937, page 72, 1 illus.

Towards the Flying Car. American-built Waterman Arrowbile. Wings are quickly detachable and the three-wheeled nacelle driven as a motor car by the 6-cylinder Studebaker automobile engine in the back. Aeroplane, March 24, 1937, page 350, 3 illus.

TWA, Inc. New DST Douglas transport for TWA. Performance and technical improvements. Western Flying, April, 1937, page 38. Brief.

U. S. S. R.

Soviet Aviation Today. P. M. Magruder and L. Zacharoff. Civil and military aircraft and engines, work of the "Osoaviakhim," the administration of civil and military air fleets, and dirigible construction. Performance, engines, and armament of a few military airplanes referred to. Aero Digest, April, 1937, pages 24–27, 12 illus.

Air Transportation

The Copeland Recommendations. Review of recommendations put before the Senate by the Commerce Committee. U. S. Air Services, April, 1937, page 35.

The Fourth Base Ship. The Friesenland, fourth depot ship for transatlantic flying boats of Deutsche Luft Hansa, recently launched, will be stationed off the Azores as one of the bases of operation of the North Atlantic mail service to be inaugurated next summer. Brief reference. Aeroplane, March 24, 1937, page 360.

Air Transport Strides Ahead. A. R. Boone. Personnel problems to be solved in operating the four-engined airplanes which will soon be spanning the Continent at higher altitudes and increased speeds, and on long ocean flights. U. S. Air Services, April, 1937, pages 13–16, 32, 2 illus.

A Down-Covered Fledgling Starts Down Under. R. S. Findley. Study Pan American Airways has been making of the proposed air route from Honolulu to New Zealand with a map and drawing of the Sikorsky S-42B flying boat surveying the route. U. S. Air Services, April, 1937, pages 11–12, 3 illus.

Similar shorter article. Western Flying, April, 1937, page 17, 1 illus.

Winter Sports at the North Pole. Five Soviet airplanes left Moscow, March 22 on their way to the North Pole. Ten scientists and a number of assistants, including sleigh dogs, each with a parachute, are to be dropped over the side to establish a permanent settlement there. Idea is to establish a midway station for a polar air route from Moscow to San Francisco. Building materials, scientific apparatus, and provisions are to be put down there. Brief note. Aeroplane, April 14, 1937, page 424.

Balloons

Some Problems Connected with a Stratosphere Ascension. Jean and Jeannette Piccard. Air conditioning and weighing-off problems, and materials. Brief abstract from Industrial & Engineering Chemistry, 27, 121 (1935). Journal Franklin Institute, April, 1937, pages 513–515.

Gliding

Sailplane versus Aeroplane. Value to airplane pilots of experience in flying gliders. Flight, March 18, 1937, pages 268a–268d, 6 illus.

The Goeppingen Wolf and Minimoa Gliders. Characteristics. L'Aérophile, March, 1937, page 58, 3 illus.

The Pedal-Plane. Bossi pedal-driven Aerocycle which flew a circular course of 1000 meters. December 23. Few details. Aeroplane, April 14, 1937, page 438, 4 illus.

Propellers

An Infinitely Variable Gear. Paterson hydraulically-controlled mechanical torque converter described, has infinitely variable characteristics over any range, is adapted to propeller hubs, and provides semi-automatic variation of torque ratio. Flight, March 11, 1937, page 238, 2 illus.

McCauley Aviation. New drop forged solid steel propeller blades suitable for engines between 170 and 300 hp. now ready for commercial use. Brief reference. Western Flying, April, 1937, page 34.

Propeller Twisting. Oilgear machine for forming propeller blades. Few details. Automotive Industries, April 10, 1937, page 573.

The Single Bladed Propeller. A. S. Pierce. Everel single-bladed propeller. Design and results of flight tests. Western Flying, April, 1937, pages 18–19, 2 illus. Aero Digest, April, 1937, page 87, 1 illus.

Aircraft Instruments

Askania in England. Latest type of Askania electrically-heated pilot head, and a distant-reading type of compass, the repeater for which is operated by compressed air. Few details only of instruments to be sold in England. Flight, April 15, 1937, page 378.

The Principles and Practice of Automatic Control. First issue—Further description of British automatic aircraft pilot, explaining in detail the origin of damping component and aileron control. Second issue—Sperry automatic pilot. Long description and discussion of the damping effect of time lag. Continued. Engineer, April 9 and 16, 1937, pages 408–409 and 438–439, 9 illus.

Engine Testing Instrument Panel. Temperature readings from 22 points on the engines are indicated on the elaborate instrument-panel test desk devised by United Air Lines to test the two 1150-hp. engines on its new Douglas Mainliners. Few details. Aero Digest, April, 1937, page 74, 1 illus.

The Principles and Practice of Automatic Control. First issue—Minorsky automatic pilot for ships. Second issue—British automatic aircraft pilot developed at the R.A.E. and made by Smith's Aircraft Instruments, Ltd. Siemens autopilot for aircraft also discussed. Continued. Engineer, March 26 and April 2, 1937, pages 352–353 and 380–382, 13 illus.

Airport Equipment

Illuminated Wind Tee. Kirsten Hi Tensity neon-lighted wind tee installed at Boeing Field visible from 3 to 5 miles under average conditions from 1 to 2 miles in foggy weather. Few details. Aero Digest, April, 1937, page 74, 1 illus. U. S. Air Services, April, 1937, page 32.

Modern Airplane Hangars of Steel and Reinforced Concrete. A. Mehmel. Construction of modern hangars described. V.D.I. March 6, 1937, pages 290–294, 32 illus.

The Refueling of Airplanes and Seaplanes. J. Retel. Fixed and movable posts for refueling airplanes and seaplanes, including ground apparatus and apparatus to be taken on board aircraft are discussed and apparatus installed at Saint-Nazaire for fueling seaplanes described. L'Aéronautique, January, 1937, pages 9–14, 10 illus.

Aerodrome and Airway Lighting. British requirements for airport lighting, and British equipment. To be continued. Engineering, April 16, 1937, pages 428–430, 5 illus., and 5 on suppl. plate.

Basra Buys British. Specially-built Merrweather combined crash tender and fire engine. Few details. Aeroplane, March 31, 1937, page 389.

De-Icing Equipment

The Accidents to No. 102 (B) Squadron. "De-icing equipment is in the experimental stage, and so far as is known, is not in everyday use in any Air Force abroad." Statement in an official explanation for accidents due to icing which caused a R.A.F. squadron commander to lose touch with his squadron and interfered with radio communication. Brief. Aeroplane, April 7, 1937, page 400.

Electrical Equipment

Electricity Aloft. S. P. Johnson. Aircraft electrical equipment for lighting, miscellaneous devices, engine equipment, retracting units, power-supply problems, and some special problems peculiar to aircraft. General discussion. Electrical Engineering, April, 1937, pages 406–410, 4 illus.

Lighting Equipment

Blind Landing in the United States. Two devices are said to have been constructed in the United States for guiding aircraft along an inclined plane in landing in fog. One uses infrared rays in place of luminous markers and the other radio-telegraphy emissions. The method using luminous markers is explained, with references to the two new devices, and compared with the U. S. Army Air Corps and Department of Commerce systems of blind landing previously discussed. Rev. de l'Armée de l'Air, January, 1937, pages 112–113.

Miscellaneous Equipment

The Finishing Touch. British aircraft accessories and personal equipment for the private owner. Flight, March 18, 1937, pages 275–276.

Fire Systems of Lighter Weight. New improved valve for Lux airplane fire extinguishing systems, developed by Walter Kidde and Company, allows a weight reduction of about 12 per cent. Brief reference. Aero Digest, April, 1937, page 72.

Fire-proof Rescue Suits. Asbestos suits have been adopted as rescue equipment for the R.A.F. and 200 have been ordered. Two airmen with the fire tender will wear the lower portion of the suits and in event of a crash will quickly slip on the top. Brief ref. Aeroplane, March 31, 1937, page 389.

Metals

Aircraft-Engine Materials. J. B. Johnson. Discussions following paper are entitled: "Supplementary Information on Light-Alloy Castings," G. D. Welty; "Contributes to Data on Steel-Backed Bronzes," G. A. Zink; "Considers Hidden Defects in Steel," H. Wysor; and "Case-Hardening and Chromium Plating Data Requested," H. K. Cummings. (See TECHNICAL DATA DIGEST, February 15, page 27 for abstract of preprint.) S.A.E. Jour. (Trans.) April, 1937, pages 153–164, 8 illus., 3 tables.

Specificationitis. Multiplicity of materials specifications approved by the Air Ministry for aircraft construction is said to be a cause of delays in producing British military aircraft on schedule. Bristol lists the number as 133. Numbers of steel-, aluminum-, and magnesium-alloy specifications given. Brief editorial. Flight, April 1, 1937, page 315.

Non-Ferrous Alloys

A B.S.I. Publication. Revised edition of B.S. Specification T. 51 for high-pressure seamless copper tubes for aircraft work, issued by British Standards Institution. Few details of revision. Flight, April 8, 1937, page 351.

Riveting

Riveting of Aluminum and Its Alloys. Aircraft riveting. Shear strengths and safe shear design stresses for A17S-T, 17S, 53S-W, 53S-T, and 53S driven aluminum rivets; identification marking; chamfered shank ends; retarding rate of age hardening; safe design value of one rivet in single shear; safe bearing design stresses for driven rivets; design of riveted joints; maximum spacing of rivets in compression members and spacing for maximum bearing strength; caulking of riveted joints; correct fit of the bucking tool on the manufactured head; heat treating and driving of rivets. Aero Digest, April, 1937, pages 44–45, 3 illus, 3 tables.

Welding

Non-Destructive Inspection of Welded Tube Assemblies Used in Aircraft Construction. A. Petiniaud and R. Schmidt. Recruiting and inspection of personnel, inspection of materials and regulation of welding procedure, current practice in control of welding procedures, non-destructive inspection, principle of radiographic inspection of tubular assemblies, nature and thickness of the filter, practical application of the method, interpretation of radiographs of welded joints, and generalization of welding procedure to aeronautical construction. L'Aéronautique, January, 1937, pages 3–8, 10 illus.

Parachutes

The Four Winds. Parachutes were used in recent tests at Susaki airport, Tokyo, to reduce the distance covered by a machine when landing. They were attached to the tail and opened just before landing. Brief reference. Flight, April 1, 1937, page 323.

Photography

Aerial Camera. Skyview Model D focusing-type aerial camera fitted for work in the air and on the ground and having variable shutter speeds. Aero Digest, April, 1937, page 74, 1 illus.

Engine Design and Research

Carburetion of Engines for Long Range Flight. W. L. Losson. Requirements of carburetors for long range cruising and list of types according to suitability, characteristics of a normal carburetor that does not automatically compensate the mixture, and characteristics of various means of controlling the mixture are discussed. Details are given of a carburetor, tested by Wright Aeronautical Corporation, in which a diaphragm mechanism replaces the float mechanism. Compensation within 10 to 15 per cent up to 15,000 ft. is provided and ice formation in the venturi created by vaporization of fuel is eliminated. S.A.E. Preprint for Meeting, March 11 and 12, 7 pages, 4 illus.

Cast Crankshafts. H. J. Gough. Static, impact, hardness, and supplementary fatigue test data obtained on alloy steel, copper-chromium iron, inoculated iron, chrome-molybdenum iron and nickel-chrome iron. Results of research undertaken at the National Physical Laboratory. Abstract, Institute of Automobile Engineers paper. Engineer, March 26, 1937, pages 360–361, 2 illus.

The Design of Metal Fins for Air-Cooled Engines. A. E. Biermann. Considerable improvement in heat transfer of conventional aluminum fin designs is possible by correctly proportioning fin dimensions, according to the analysis of N.A.C.A. data given. Correctly proportioned aluminum fins will transfer more than 2 1/4 times as much heat as steel fins for same weight and pressure drop. Minimum weight, minimum pressure drop, or minimum power for cooling, practical limits of fin dimensions, maximum overall heat-transfer coefficient for given weight and pressure drop, improvement in heat transfer, and power required for cooling are determined. S.A.E. Preprint for Meeting March 11 and 12, 12 pages, 12 illus.

The Compression Ignition Aero-Engine. E. L. Bass. Criticism of previous articles (February 26 issue) estimating the value of the compression-ignition engine for civil aviation, and giving further engine data comparing engines using 87 and 100-octane fuel with compression-ignition engines. Engineer, April 9, 1937, page 423, 3 illus, 1 table.

On a Formula of Rayleigh for Velocity Potential. N. W. McLachlan and A. T. McKay. Remarks of S. Ballantine in previous paper regarding the formula due to Rayleigh used extensively to calculate the radiation from a piston in an infinite baffle are criticized and author's reply given. Journal Franklin Institute, April, 1937, pages 501–509, 3 illus., 22 equations.

Spark-Plug Adapted for Measuring Cylinder-Head Temperatures. G. D. Boerlage and A. G. Cattaneo. (See Technical Data Digest, February 15, page 43 for abstract of preprint.) S.A.E. Jour. (Trans.) April, 1937, pages 151–152, 172, 5 illus.

A Friend from Connecticut. "Power Plant Trends," a paper to be presented by G. J. Mead before the Royal Aeronautical Society, briefly outlined. Aeroplane, April 14, 1937, page 423.

The In-Line Air-Cooled Aircraft Engine. A. T. Gregory. Characteristic features of this type regarding cooling, airplane installation, weight, valve gear, valves per cylinder, and lubrication. Data includes: weight analysis of the Ranger SGV-770 engine installation, and weight comparison of 9-cylinder radial and V-12 inverted-inline aircooled engines. Drawings illustrate arrangement for cooling inline engines, types of air scoops, airflow conditions around spark plugs and over cylinder heads, and rocker roller-bearing loading. S.A.E. Preprint for Meeting May 4–9, 1937, 20 pages, 7 illus., 2 tables.

Radiators at Low Speeds. M. Victor. Results of Wright Field experiments on aircraft-engine radiators, described recently by Weldon Worth before the S.A.E., are quoted, discussed, and compared with results obtained by Liore et Olivier and Hispano Suiza. Les Ailes, March 18, 1937, pages 6–7, 10 illus., 3 tables.

Radio Shielding. H. E. Gray. Importance of bonding and shielding on airplanes, and construction of shielded ignition harness. Effect of the latter on energy available at the spark plug under various pressures; results of tests on a complete ignition harness built of individually shielded conductors (used on large radials), and on standard manifold harness employing unshielded wire; certain peculiarities of shielded and unshielded plugs; and problems of heat, moisture, good mechanical connections, and magnetic shields. Author is supervisor of Radio Equipment, American Airlines. S.A.E. Preprint for Meeting May 4–9, 1937, 13 pages, 4 illus, 2 tables.

Trend of Air-Cooled Aero Engines in the Next Five Years. A. H. R. Fedden. Main factors governing the trend, four types of engines to meet military and large civil-transport requirements, and most promising layouts for these four types. Types of aircraft and probable main aircraft categories; engine categories to meet new aircraft demands; comparison of 1500-b.hp. aircooled radial (100 octane) and compression-ignition engines; engine layouts from the geometric and aerodynamic aspects in regard to drag due to cooling air flow and to installation of nacelle on a wing, and drag equivalent of power-plant weight; and standardization of complete power units. S.A.E. Preprint for Meeting, May 4–9, 1937, 36 pages, 12 illus., 4 tables.

Engines

The Cirrus Major 150. New British engine develops 150 hp. at 2450 r.p.m. and weighs complete 2.16 lb. per hp. Aeroplane, March 17, 1937, page 329, 5 illus.

Diesel Engines for French Aircraft. M. A. Mandel. Characteristics of four makes of aircraft Diesel engines exhibited at the recent Paris Show. Brief abstract, French Society of Automobile Engineers paper. Automotive Industries, April 10, 1937, page 560.

Engines for 1937. Photographs of 15 aircraft engines and table of specifications. Aviation, April, 1937, pages 72–75, 15 illus., 1 table.

Improvements in the Lycoming Engines. New Lycoming D series radial aircooled engines rated at 260 hp. with a 6.5:1 compression ratio at 2300 r.p.m. at sea level. Improvements and specifications. Aero Digest, April, 1937, page 54, 3 illus., 1 table.

Menasco Mfg. Co. Fifteen Menasco B-6 160-hp. engines have been ordered by Dutch Navy for use in its training planes. Brief reference. Western Flying, April, 1937, page 34.

The Right Engines for Light Airplanes. Aero Engines, British Anzani, Carden, Carden-Baynes, Cirrus, Coventry Victor, DeHavilland, J. A. P. Phillips and Powis, Pobjoy, Scott, Villiers-Hays and Weir engines for aircraft. Specifications. Flight, March 18, 1937, pages 282–285, 16 illus.

Wright Aeronautical. New Cyclone R-2600 twin-row engine believed capable of producing 1500-hp. Pan American has ordered 26 and T W A 32. Western Flying, April, 1937, page 34.

An Advanced Four-In-Line. Increased power and structural revision of the Cirrus Major 150 engine. Long description. Flight, April 1, 1937, pages 326a–326c, 10 illus., 1 table.

A Combination and a Form Needed. Improved Villiers Maya inline engine developing 135 hp. at 2700 r.p.m., and performance attained with a Miles-Whitney Straight plane equipped with it. Aeroplane, April 14, 1937, pages 445–446, 4 illus.

Cruel to be Kind. Bristol Perseus III sleeve-valve airplane engines, in production for the Air Ministry and Imperial Airways, have been made to suffer 100 hours overload tests at high outputs, high "revs" and full throttle, both with and without a high-ratio supercharger impellor. Tests passed successfully. Brief reference. Aeroplane, March 31, 1937, page 389.

High Rated Radials. Details of British Alvis engines cover: Alcides 18L 18-cylinder double-bank radial (maximum output 1502 hp., cruising rated power 1300 hp. at 2150 r.p.m.); Alcides Major (fully supercharged for 13,000-ft. rating); Pelides and Pelides Major (1000 hp. at 5000 ft. and 13,000 ft.); and Maeonides Major 14M small-diameter two-row fully-supercharged radial following latest Continental practices (680 hp. at 13,000 ft.). Long description of Pelides, particularly, and modifications from Gnôme-Rhône engine types. Flight, April 15, 1937, 370a–370d, 11 illus., 1 table.

Notes. Lorraine Algol fuel-injection engine with a Lauret fuel-injection pump is being tested in a Morane 230 two-seater trainer. Brief reference to French Air Ministry tests at Villacoublay. Luftwissen, February, 1937, page 54.

Power for the L.Z. 130. Mercedes-Benz 900/1200-hp. 16-cylinder vee Diesel engine for the new Zeppelin weighs 4400 lb. Two views only. Flight, April 8, 1937, page 350, 2 illus.

Technical Notes. Clerget 500-hp. 14-cylinder heavy-oil engines have passed ground tests satisfactorily and have been installed in a Morane 450 pursuit, Wibault-Breguet, and Bloch 200 for flight testing. New English Shackleton-B 4-cylinder 2-cycle engine (500-cu. cm. displacement, and 50 hp. at 3000 r.p.m.) has been satisfactorily tested. Brief references. Les Ailes, March 25, 1937, page 7.

Tests of Heavy-Oil Engines in Flight. Bernard Lilloise 86 and Junkers Ju-86 airplanes equipped with Junkers engines and their performances. Few details. L'Aérophile, March, 1937, pages 65–67, 8 illus.

Up and Up. Tests are now being made with the Rolls-Royce liquid-cooled airplane engine intended for the sister machine of the Bristol 138 monoplane which put the World's height record up to 50,000 ft. Brief reference. Aeroplane, March 31, 1937, page 366.

Various Notes. Fairchild 24-cylinder H-type aircooled engine. A few details with remark by S. Fairchild that heavy-caliber rapid-firing weapons had been found impractical in radial engines. U. S. Naval Inst. Proc., April, 1937, pages 592–593.

Parts and Accessories

Direct Starting of Engines by the Lorraine Auxiliary Group. M. Victor. Two-cylinder horizontal flat-twin engine of 216 c.c. total cylinder displacement develops 6 hp. at 4500 r.p.m constant speed. The Labinal or Wageor Confinhal 1800-watt generator or a 240-watt generator, the Lorraine supercharger, and a Rellumit PB-30 double-piston pump are driven directly from the crankshaft. Long description of each and results of endurance and starting tests. Les Ailes, March 25, 1937, pages 6–7, 3 illus.

England Shows How. British two-stage automatic mixture control invented some time ago by R. J. Penn of R.A.E., Farnborough. It is now being supplied for Service machines, takes complete charge of mixture strengths, irrespective of machine heights, and is said to be the only completely automatic mixture controller, whether constant-speed propeller is used or not. Standard practice in America criticized. Brief note. Aeroplane, April 7, 1937, page 419.

New Fuel Induction System. Continental Motors Corporation fuel-induction system. Graph shows differing efficiencies of the new Continental induction system and older ones. Brief. Automotive Industries. April 17, 1937, page 602, 1 illus.

Technical Notes. Fuel-supply system for Bradenburg engines has been mounted in a 35-hp. Mengin aviation-type 2V engine. By this system Brandenburg hopes to gasefy and pulverize the entire range of liquid fuels between ordinary gasoline and gas oil. Few details. Les Ailes, March 18, 1937, page 8.

A Sedative. Burgess F. K. silencer for aircraft engines described was developed at the Royal Aircraft Establishment, and works on the principle of reflecting the sound waves out of phase. Silencer can be modified to obtain a required reduction in noise, or to be within a definite weight limit or back pressure. Aeroplane, March 24, 1937, page 362, 1 illus.

Engine and Fuel Testing

The Inclinable Bristol Test Stand. Stand for testing engines in diving and stalling positions. Photograph only. Rev. de l'Armée de l'Air, February, 1937, page 238, 1 illus.

Up-to-the-Minute Engine Testing. Test-stand layouts at the Alvis works, England, which is now going into production with big radials under Gnôme Rhône license. Very long description. Flight, April 8, 1937, pages 348c–348g, 10 illus.

Apparatus for Measuring Shaft Operation in Aircraft Engines. K. A. Luerenbaum. Requirements for taking measurements on an engine shaft during operation and two DVL measuring devices by means of which torque characteristics are recorded on a strip of film in full scale, the shaft itself serving as a measuring spring. With the recording torsiometer torsional vibration measurements were made on engine drives for motor vehicles, vessels and aircraft under operating conditions. With the other torsion recorder developed for the Junkers aircraft Diesel engine, measurements were successfully carried out at considerable altitudes. DVL report. V.D.I. March 20, 1937, pages 353–356, 8 illus.

Reaction Propulsion

Research On the Reaction Motors. R. Pris. Expressions for rocket reaction, power consumed, and for the thermal, propulsive, equivalent-propeller, and total efficiencies. Rockets using liquid fuel are discussed in regard to the rocket head and propulsive efficiency. To be continued. L'Aérophile, February, 1937, pages 34–36, 6 illus., many equations.

Fuels and Lubricants

Effect of Addition Agents in Lubricating Oil on Piston and Ring Performance in Gasoline and Diesel Engines. C. M. Larson. Some results of tests with compounded aircraft lubricating oils correlated in airline operation with full-scale gasoline engine tests are discussed, tests with the single-cylinder official Caterpillary Diesel test engine are described, and predictions made for the future lubricant. S.A.E. Preprint for Meeting, April 21, 1937, 12 pages, 20 illus., 3 tables.

Engine and Laboratory Tests of Stability of Aviation Oils. O. C. Bridgeman, T. T. Neill, and E. W. Aldrich. Development of a suitable laboratory method for determining oil stability to give results significant in terms of service changes in these oils when used in aviation engines. One method described heats the oil with the surface exposed to air but without aeration and the other under aerating conditions. Results of laboratory and engine tests on 22 aviation oils (Grade 3080, 3100, 3120, and 3150) are given and correlation of engine and laboratory data discussed. Part of program of NACA Subcommittee on Aircraft Fuels and Lubricants. S.A.E. Preprint for Meeting, March 11 and 12, 1937, 26 pages 40 illus., 4 tables.

Aircraft Radio

Aero Radio Digest. Pan American long-range direction-finding apparatus for ground stations to be manufactured by Bendix Radio Corporation, Bureau of Air Commerce Z marker beacon, United Air Lines flying radio laboratory, and radio meterorograph developed by the Bureau of Standards for use in the meterological service of the U. S. Navy. Long descriptions of marker beacon and meterorograph only. Aero Digest, April, 1937, pages 62, 64, 6 illus.

Bendix to Produce New PAA Direction Finder. Brief reference to this instrument and photograph of United Air Lines airplane equipped with several inventions being tested to eliminate rain and snow static interfering with two-way aircraft radio reception (few details in the caption). U. S. Air Services, April, 1937, page 28, 1 illus.

Converts Airliner Into "Flying Laboratory." Equipment and plane for testing radio and electrical equipment for United Air Lines. Brief. Western Flying, April, 1937, page 40, 2 illus.

Simultaneous Radio Range and Telephone Transmission. W. E. Jackson and D. M. Stuart. Various methods of obtaining simultaneous service for the airways. Effect of linear and square-law detection used with single side-band and double side-band transmission of range tone analyzed. Single side-band method appears to offer the most practical solution to the problem when used with a linear detector. Detector distortion for single and double side-band transmission computed. Authors are with the Bureau of Air Commerce. Proc. Inst. Radio Engrs., March, 1937, pages 314–326, 12 illus., 9 equations.

Ultra-Short-Wave Propagation Along the Curved Earth's Surface. P. von Handel and W. Pfister. Penetration of ultra-short-wave radiation beyond range of optical sight is dependent on diffraction and refraction of rays. An analogy to optics is made, and diffraction calculated by various methods. Curves give the decrease of field intensity with distance for various elevations in range of wave lengths of interest. Curves are substantiated by airplane measurement. Measurements of the influence of refraction included. Report of DVL (German Aeronautical Research Institute). Proc. Inst. Radio Engrs., March, 1937, pages 346–363, 20 illus., many equations.

The W. I. T. "Air-Track" System of Instrument Landing. System developed by Washington Institute of Technology provides the pilot with a constantly and automatically defined three-dimensional gliding path from a point in space to a selected runway within the airport limits. Entire ground equipment is compactly mounted in an automobile trailer. Long description. Aero Digest, April, 1937, pages 60 and 64, 4 illus.

Application of the RC-5 Busignies Radio Compass for the Automatic Piloting of Aircraft. Parts and connections of radio compass illustrated and a French patent analyzed. Rev. de l'Armée de l'Air, February, 1937, pages 229–231, 1 illus.

Meteorology

Flashes. Possibility of constructing whistles with a vigration capable of shaking the fog out of the atmosphere, recently discussed at a scientific meeting. Brief ref. Western Flying, April, 1937, page 42.

Possibilities of Soaring Flight in Winter. F. Hoehndorf. Meteorological conditions in winter for soaring flight. Report of German Research Institute for Soaring Flight. Luftwissen, February, 1937, pages 33–36, 5 illus., 1 table.

Air Forces

Flashes. Most recent estimate of fighting craft in Europe, made by W. R. Enyart of the N. A. A., shows 25,000 craft now in service with a possible production of 20,000 more this year. Brief reference. Western Flying, April, 1937, page 42.

World Air Power. Military line-up for 1937. Chart shows probable number of military aircraft in lands of the major powers and probable first-line strength. Order given as Russia, Germany, Italy, France, Great Britain, United States, and Japan. Aviation, April, 1937, page 82, 1 illus.

Australia

Well Alight in Australia. Extracts from Australian newspapers on the controversy over whether North American Na. 16 or British airplanes should be constructed in Australia for the Royal Australian Air Force. Aeroplane, April 14, 1937, pages 425–426.

Canada

Canadians in the R.A.F. About 150 airmen have left Canada during the last few months for Commissions in the R.A.F. Brief reference. Aeroplane, March 31, 1937, page 368.

A Citizen of the Empire. H. G. Scott. Different opinions prevalent in Canada on assistance it should render England in the next war. Brief discussion of Cy Caldwell's article in Aero Digest, January, entitled "The Influence of Air Power on History" which pointed out the extent to which England is vulnerable to attack by air. Aeroplane, April 14, 1937, page 426.

The Four Winds. Three Northrop Delta Mark 1 twin-float seaplanes are being built by Canadian Vickers, Ltd. for the Royal Canadian Air Force. Brief reference. Flight, April 8, 1937, page 345.

Foreign News in Brief. Estimates for 1937–38 for aviation, number of new military airplanes to be purchased, and increase in R. C. A. F. personnel. Brief reference. Aero Digest, April, 1937, page 90.

Czechoslovakia

The Question of Czechoslovak Aerodromes. Statement that Russians had much to do with Czech airports and Czech aviation, quoted in a recent article, is refuted by Lieut. Col. J. Kalla. Facts are given regarding Russian officers on the Czech Army, airports alleged to have been built by Russian engineers and workmen, Czechoslovak-Soviet military pact, and military personnel in the Soviet Legation in Prague. Aeroplane, April 14, 1937, pages 429–430.

France

French Aviation Budget for 1937. Amounts allotted to the various main divisions of French aviation for 1936 and for 1937, showing an increase in 50 per cent for the 1937 budget. L'Aérophile, March 1937, pages XIX and XX.

Program of Aircraft for Naval Aviation. Captain P. Barjot. Many types of aircraft for the French naval air services are outlined with a table of aircraft in service. Naval and coastal aviation, and duties of aircraft-carrier and coastal aviation units are analyzed.

Three types of aircraft are proposed, namely, catapultable seaplanes for naval observation, interchangeable land-seaplanes for observation-torpedoing, and light bimotored land planes with retractable landing gear for simple coastal observation, maneuvering toward observation-bombardment in the case of narrow seas. Power, maximum and cruising speeds, range, and special features are given for the Loire 130, Le H.43 catapultable observation seaplanes, the Latecoere 29, Dornier Do 22 or Do C.3 and Blackburn Shark observation-torpedo seaplanes, and the Leavsseur P.L.101 single-engined and Avro Anson bimotored purely observational aircraft. This comparison shows that the Dornier seaplane and bimotored Avro Anson give the best performance. Rev. de l'Armée de l'Air, February, 1937, pages 126–152, 18 illus., 2 tables.

Report of the Aviation Budget for 1937. Personnel in the French Air Forces, number of airplanes, training schools, and eleven main divisions of the French aviation budget for 1936 and 1937. Rev. de l'Armée de l'Air, February, 1937, pages 215–216, 2 tables.

Germany

Militarization of Gliding in Germany. Gliding in Germany during 1936. Rev. de l'Armée de l'Air, February, 1937, pages 210–214, 6 illus.

The Four Winds. Experimental "hookings-on-to" and "droppings-off-from" the Zeppelin Hindenburg have been made by Colonel Udet in a Focke Wulf Steiglitz biplane. Brief ref. Flight, March 25, 1937, page 299.

Great Britain

Air Power and Its Employment. Air Vice Marshall Gossage. First issue—Air power in conjunction with naval and military operations and in coast defense. Assistance which could be rendered by the R. A. F. in army operations, offensive and defensive operations, example of Palestine, and parachute operations.

Second issue—Air power in Imperial defense overseas. Air forces as a primary arm, air control in Iraq, Palestine problem, forces in India for defense in frontier troubles and/or war with Afghanistan, and for defense in case of war with Russia, provision of Imperial air routes to insure mobility of the air forces, and the possibility of mutual reinforcement along these air routes as conferring a striking economy of force. Third, London University lecture. Aeroplane, March 17 and 24, pages 324–325 and 345–346.

Largest Air Estimates Ever. Points from Sir Philip Sassoon's speech in the House of Commons introducing the Air Estimates, and referring briefly to first-rate quality and quantity in R. A. F. recruiting, Browning and new Vickers guns to be used on aircraft, research into high-efficiency fuels, sleeve-valve engine developments, aircraft production delays, shortage of skilled employees, ordering "off the board," and the Air Ministry's relation to the contractors. Editorial dealing with question of unified or divided control of air defense. Flight, March 25, 1937, pages 305–306 and 291–292. Aeroplane March 24, 1937, pages 355–357.

On the Air Estimates. C. G. Grey. First issue—Numbers of personnel; air force pay, engineer officers; relatively small increase in equipment and accountant branches; aircraft industry; airplanes and engines; the shadow industry; Farnborough increase to £426,500 (as compared with £360,000 last year) and criticisms, accessories and gadgets, photography and lack of aircraft photographic equipment; question of air cannons, electricity, oddments of research; airplane soft goods; transport; fuel and oil; inventors' rewards; and airships. A table compares Air Estimates of 1937 and 1936 and the amounts allotted the ten divisions of the effective services.

Second issue—Works and Buildings estimates amounting to £45,028,180 (£10,252,700 to be spent at home); improvements planned to Royal Air Force stations in Great Britain and abroad, and to the Calcutta-Singapore air route; amounts allotted to Medical Services, Reserves and Auxiliary Air Forces, and to civil aviation; and cost of the Air Ministry. Aeroplane, March 17 and 25, 1937, pages 316–321 and 351–354. 1 table.

The White Paper on the Air Estimates. On April 1, 1937, the R. A. F. will consist of 100 squadrons at home, 20 with the Fleet Air Arm and 26 squadrons overseas, and strength of 4850 officers and 51,000 men. Parts of Memorandum quoted. Aeroplane, March 17, 1937, page 317.

The Air Estimates Resumed, and In Committee. Further debate in the House of Commons. The second issue quotes other portions of the debate with editorial comments. Aeroplane, March 31 and April 7, 1937, pages 371–372 and 395–398.

Air Power and Its Employment. Air Vice Marshall Gossage. Problems of home defense as the primary and most important duty of the Royal Air Force. Expansion of the R.A.F., the offensive and defensive elements in air warfare, and passive defense are discussed. Concluded. Aeroplane, March 31, 1937, pages 369–370.

Bombay Bombers for Belfast. Orders for the Bristol 130 Bombay bomber-transport have been placed with Short and Harland, Ltd. of Belfast. The Bombay is designed for long-range bombing or to carry 24 fully-armed infantrymen. Besides gun turrets at nose and stern, the bomber carries auxiliary armament amidships. The Bristol Blenheim high-performance bomber will also be built in large numbers by the shadow factories. Brf. ref. Aeroplane, March 31, 1937, page 366.

Collisions in the Air. During the last 12 months there have been 15 collisions in the air between R.A.F. airplanes. Brief reference only to measures being taken to avoid collisions. Aeroplane, March 31, 1937, page 367.

"Expansion" Trainers. Air Ministry has placed orders for Miles Magisters, DeHavilland Dons and twin-engined Airspeed Oxfords, each to cover a specified range of duties for the training of pilots for the R.A.F. Brief reference. Flight, April 8, 1937, page 339.

Fleet Exercises. British tactical training exercises for cooperation of aircraft and submarines in locating and attacking a fleet and to exercise the Fleet in counter measures. Few details. Aeroplane, March 31, 1937, page 367.

More About the Cases for Spectacles. Present standards of vision for British pilots in use today, and the advisability of having partially-sighted (without glasses) squadron of airline pilots. An article by F. D. Bradbrooke entitled "The Training of the Eyes" follows. Aeroplane, April 7, 1937, pages 407–409.

Holland

Foreign Service News. Dutch Army and Navy are to be strengthened, and a second group of 39 bombing airplanes for the Netherlands East Indies is under consideration. Brief ref. Aeroplane April 14, 1937, page 434.

Italy

Foreign Service News. The Italian government is said to have offered the government of Saudi Arabia a gift of three airplanes as a token of good will, and skilled labor has been sent from Eritrea to Jeddah to build an airport. Brief reference. Aeroplane, April 14, 1937, page 434.

Japan

Naval stations and naval air stations shown on map. U. S. Naval Inst. Proc. April, 1937, pages 583–584, 1 illus.

Various Notes. Japanese general plan of air combat is complete destruction of enemy air bases before enemy planes are able to attack the Japanese mainland. Opinion that as a race Japanese are not apt aviators and fact that the Japanese Air Force is on a diet also referred to. U. S. Naval Inst. Proc. April, 1937, pages 586–587.

Mexico

Foreign News in Brief. Airplane assembly plant is to be established by the Mexican Ministry of War and Marine, and imports of military aircraft and engines will be limited to engines and wings. Brief reference. Aero Digest, April, 1937, page 92.

Portugal

Foreign Service News. Decree providing for Reserves for the Portuguese Air Arm. Brief note. Aeroplane, April 14, 1937, page 434.

Spain

Flashes. Douglas aircraft are the supreme fighting planes used by Loyalist Forces in Spain, according to A. Malraux. Brief reference. Western Flying, April, 1937, page 42.

SWEDEN

The Four Winds. A number of Mercury-engined Gloster Gladiators have been ordered for the Swedish Air Force. Brief reference. Flight, April 1, 1937, page 323.

Siemens Sh. 14-A4 160-hp. 7-cylinder radials have been ordered to power Focke-Wulf Stieglitz trainers for the Swedish air force. Brief reference. Les Ailes, March 25, 1937, page 11.

TURKEY

Foreign Service News. General Inönü, Prime Minister of Turkey, is said to aim at 1000 airplanes and 15,000 trained pilots for the regular establishment of the Turkish Air Force. Brief reference. Aeroplane, April 14, 1937, page 434.

U. S. A.

Effects of Mechanization. Numbers in a division of cavalry and in an American mechanized brigade having approximately the same firing power are compared. Brief abstract from Army Ordnance, January. Rev. de l'Armée de l'Air, February, 1937, page 219.

Air Corps Improved Accident Rate. Letter from the Secretary of War to the Chief of the Air Corps commending the Air Corps on the low accident rate. U. S. Air Services, April, 1937, page 33.

The Army and the Navy. "With the American Air Services taking delivery on some eight-hundred new planes, most of them combat types, 1936 seems to show the beginning of a new era in aircraft procurement in this country." Tables and charts show number of aircraft awaited by the Army under existing contracts, Air Corps safety record, flying equipment of our Air Forces, direct appropriations for the Air Services, Air Corps flying time, appropriations for new aircraft and engines 1926–1938, production orders for airplanes and engines placed by the Navy for fiscal year 1936, contracts not completed December 15, 1936, and deliveries of production airplanes and engines, fiscal year 1936. Aviation, April, 1937, pages 80–81, 5 illus., 4 tables.

Bomber Competition. Douglas and North American bids on bimotored bombers and Boeing bids on four-engined bombers, and the possible inclusion of tricycle landing gear. Brief ref. Western Flying, April, 1937, page 30.

Flashes. Gas-powered model craft have been submitted by R. Deny to the Army for use as anti-aircraft targets. Brief reference. Western Flying, April, 1937, page 42.

Naval Appropriations. Increase made in totals for 1938 aircraft. Amounts available and how they will be employed. Brief. Western Flying, April, 1937, page 30.

The Four Winds. "An Officer of the 33rd Pursuit Squadron, U. S. Army Air Corps, recently took a Consolidated PB-2A two seater (presumably fitted with a Curtiss Conqueror and exhaust-driven supercharger) up to 39,200 ft. where he remained about 20 minutes." Brief reference. Flight, April 8, 1937, page 345.

Out in the Cold, Cold Snow. Photographs of the U. S. Army Air Corps winter maneuvers, illustrating: a Northrop attack plane being armed from a special tractor-drawn sledge and calling attention to two of the four wing-mounted Brownings; a Boeing P-26-A fighter with combined-wheel and ski undercarriage; and a Martin bomber being warmed up. Flight, April 15, 1937, page 373, 3 illus.

Air Warfare

Aerial Bombardments of Madrid. Text of a protest from the Diplomatic Corps at Madrid against aerial bombardment, note of Alvarez del Vayo on the proposal of the International Red Cross for a neutral zone in Madrid, and the Spanish inquiry made by six members of the Chambre des Communes. Brief.

Drawings show perspective and plan views of a bomber formation of multimotors (Junkers) escorted by single-seater pursuits (Heinkels) used in the war in Spain. Rev. de l'Armée de l'Air, February, 1937, pages 216–219, 2 illus.

Air Warfare in Spain. German, Italian, French, and Russian airplanes participating in the Spanish revolution and opinions of two government pilots on the respective values of these types of airplanes and the tactics carried out in the air warfare. Reference is made to a small Russian Boeing type of pursuit I-15 powered with a Wright Cyclone, and to the Douglas transports on which gun turrets have been mounted and with which military operations have been carried out. Rev. de l'Armée de l'Air, February, 1937, pages 185–198, 4 illus.

New Deal in War. Cy Caldwell. "The Air Strategist proposes to start 50,000 and possibly 100,000 fires within a space of 15 minutes to an hour's time." Destruction of London by fire by an air detachment of 500 modern bombers, each carrying 300 small incendiary bombs, is visualized as an example of how a weaker power may gain an advantage at the outset of a war. Second of a series on air power and war. Aero Digest, April, 1937, pages 21–22, 97–100.

The Operation of Large Airplanes. Problems arising in the operation of a large 18 to 20-ton military airplane in place of five small airplanes. Rev. de l'Armée de l'Air, February, 1937, pages 123–126, 1 illus.

Problems of Pursuit. Unit tactics for territorial defense, discussed by the British Commander Andrews (R.U.S.I., May, 1934); importance of the quality of pursuit airplanes, by Commander Scaroni (Aviation, October, 1935); single-engined or two-engined airplanes, by M. Rosatelli, Fiat engineer (Ala d'Italia, December, 1936); American night maneuvers with searchlights for pursuit aviation (Coast Artillery Journal, Dec. 1935). Abstracts of these articles. Rev. de l'Armée de l'Air, February, 1937, pages 207–21, 1 table.

Air Warfare in Ethiopia and Spain. Brief editorial refuting a recent Literary Digest article entitled "Planes Debunked: As War Machines They Win in Theory but Fail in Practice." U. S. Air Services, April, 1937, page 9.

Aeronautical Industry and Production

Accessories for 1937. Classified directory of principal firms that manufacture and/or distribute materials, supplies, and accessories to the aviation industry and an alphabetical industry directory. Aviation, April, 1937, page 105–144 (alternate pages).

Aviation's Monthly Table of Domestic and Export Commercial Airplane Deliveries. Aviation, April, 1937, page 96, 98, 1 table.

Bendix Corporation. Pacific Airmotive Corporation taken over by Bendix Aviation Corporation to manufacture Bendix products on the Pacific Coast and to expand present distribution facilities for aircraft and automotive accessories. Brief notes. Western Flying, April, 1937, pages 30–31.

Clogging the Wheels. Practical remedies for aircraft production delays, applying only to particular departments in an aircraft plant, and not giving any reasons why British aircraft production is being held up in general. Flight, March 25, 1937, pages 300–302, 1 illus.

Directory of Aviation Manufacturers. American aircraft manufacturers, executives, and company products. Western Flying, March, 1937, pages 26–36, 38, 40.

The Exhibitors at the Show. Airplane, engine, and affiliated exhibitors at the Second Annual Aircraft and Boat Show, Los Angeles. Western Flying, March, 1937, pages 24–25, 40.

Final Figures Much More Encouraging. Final yearly delivery of military aircraft in the United States was 1024 and a much better production schedule was made in the last quarter. Very brief editorial. U. S. Air Services, April, 1937, page 10.

The Industry. Exports for 1936, pilot and aircraft licenses, Lockheed and North American expansion plans, new Menasco factory, the D-17-W Beechcraft airplane, Fairchild 1000-hp. cannon engine, and Taylor Cub output. Brief notes. Aero Digest, April, 1937, pages 84–86.

Industry Expansion Continues. Formation of Alcor Aircraft Corporation by Allen Lockheed is referred to in a news account of happenings in the industry. Aviation, March, 1937, page 59.

Production and Exports. Deliveries of American aircraft and engines increased during 1936 to almost $80,000,000, a figure 85 per cent better than the 1935 showing. Tables and charts give: new airplane and engines licensed in 1936, and for 1925–1936; the number of planes produced (commercial, military, and transport); value of airplane and engine production for the same categories; 1936 aeronautical exports; exports of planes, engines and accessories; and monoplanes and biplanes produced in 1936. Aviation, April, 1937, pages 84–85, 4 illus., 3 tables.

Ryan Aeronautical. Production is being increased to 30 planes a month. Brief reference. Western Flying, April, 1937, page 34.